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Reference No. 54-35

CURRENT STUDIES of the EASTERN CAYMAN SEA

By

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Technical Report

Submitted to Field Projects Branch, Office of Naval Research
Under Contract Nonr-1158(00) (NR-087-031)

May 1954

APPROVED FOR DISTRIBUTION ____________________
Director

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Abstract

This report is divided into three parts. The first describes the techniques which were used on ATLANTIS Cruise 184 to measure the overall current pattern of the Eastern Cayman Sea. Of particular interest was the extensive use of free floating drogues and anchored buoys to measure subsurface currents. The specific gear, from wire clamps to aviator's parachutes, is shown. A modification of the Pritchard current cross for use from a drifting ship is described.

The second part deals with the current picture as we found it. A significant feature of the pattern is the unexpectedly large Eastward transport between Jamaica and Cuba, which turned south and ran out through Navassa Island Passage. Of equal importance was the fact that the current ran upwind for a period of more than a week before disintegrating. Various possible mechanisms which might produce such a transport are discussed.

The third part describes miscellaneous related observations made during the cruise.

CURRENT STUDIES OF THE CAYMAN SEA

Introduction

The original purpose of the ATLANTIS Cruise 184 was to test and compare several techniques for measuring currents in the ocean. The area chosen was the body of water between Jamaica and Cuba (Figs. 1 and 2), partly because of the low wind and swell, and also because the area had been previously studied by the ATLANTIS in 1933-34. The current structure as inferred from dynamic topography had been worked out by Parr (1936), and it had been studied by Dietrick (1939). In accordance with Parr's terminology, this area has been called the Eastern Cayman Sea.

The purpose of the cruise was greatly modified soon after the program began because the supposedly weak current to the west was flowing to the east at more than a knot. Much of the time was spent in attempting to verify and explore this unexpected current, and to see what might have caused it. For these reasons not all of the available instrumental methods were tested while some, like the Geomagneticelectrokinetograph (GEK), were used much more than we had anticipated.

For convenience this report is written in three parts. The first explains the techniques used in measuring currents. The second describes the current structure of the Eastern Cayman Sea as found by the ATLANTIS Cruise 184. The third part describes some additional miscellaneous measurements.

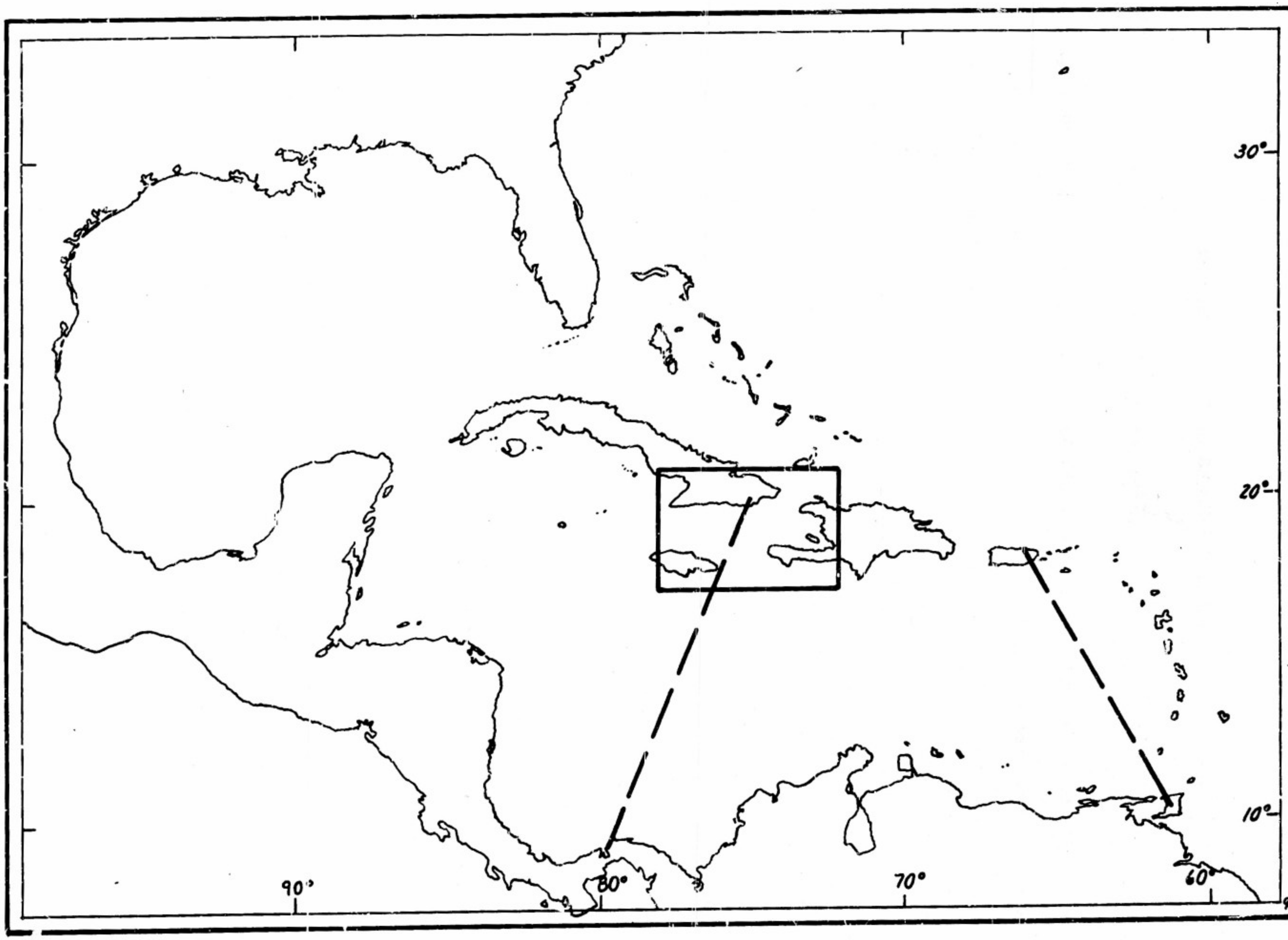

Fig. 1

Eastern Caymen Sea

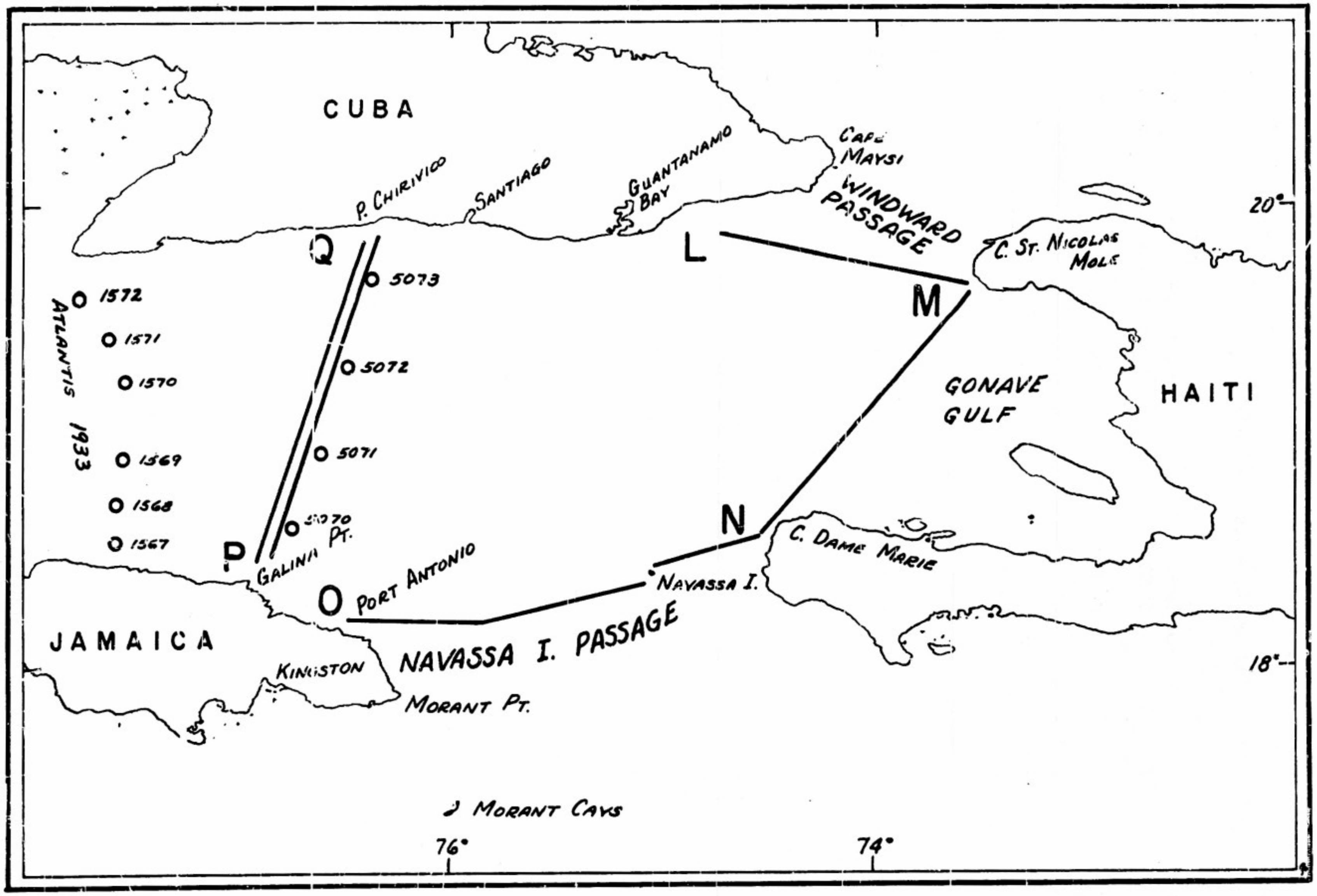

Fig. 2

Station Chart

The scientific party consisted of:

Mr. A. C. Vine	Oceanographer
Mr. R. F. Wyrick	Physicist
Mr. G. H. Volkmann	Oceanographer
Mr. A. L. Bradshaw	Physicist
Dr. J. W. Kanwisher	Physicist
Dr. R. H. Backus	Ichthyologist
Mr. J. Chase	Meteorologist
Mr. D. M. Owen	Photographer
Lt.(jg) J. Knauss	Oceanographer (Geophysics Branch, ONR)

The authors are greatly indebted to the other members of the scientific party for their very great assistance in the current measuring program. Each was a prime source of help and information in his field and contributed in large measure to the success of the trip.

The scientific party was indebted to Captain Pike of the ATLANTIS and his officers and men for their excellent cooperation.

Numerous officers and men at the Guantanamo Bay Navy Base were most helpful on logistics and also on furnishing information about local currents.

We particularly wish to acknowledge the helpful cooperation of the U.S.S. ARCADIA (AD-23) in transporting much of the scientific equipment from Guantanamo Bay back to Newport Naval Base.

Narrative of Cruise

On the 17th of March the Windward Passage was approached from the northeast after coming south through the Turks Island Passage. Going west, a run was made somewhat north of the passage and then the course was nearly doubled back to make a run across the narrowest part, between Cape Maysi on Cuba, and Cape St. Nicholas Mole on Haiti. It was here that we started what was later to become the proceedure most used throughout the rest of the trip, namely the use of BT's, GEK, and drift bottles when running, and the use of drogues and sea anchors when on station.

The 18th was spent in the middle of the passage practicing the techniques associated with putting over drogue buoys. A number of buoys were released and followed until dark. Early on the 19th, the run was made into Guantanamo Bay, Cuba. The necessary logistic support was immediately available and the ATLANTIS departed on the evening of the 20th.

A number of buoys were set 30 miles south of Guantanamo Bay on the 21st, including one successfully anchored in over 2000 fathoms where a current of over a knot to the south was found. It was impressive to see the water boiling around a buoy anchored in 2 miles of water. An attempt to obtain the vertical distribution of the current by a lowering of the large sea anchor on the trawl winch was made. The old canvas gave way and no significant results were obtained. The 23rd was spent echo sounding to the southwest of Guantanamo. This gave the scientific party a chance to discuss the course of action to be followed in view of the unexpected strength and southerly set of the current. It was decided to make a survey of the surface currents between Jamaica and Cuba.

The measurements showed a strong easterly set with a slight southerly component. On the 28th, a series of buoys was set and followed in sight of Cuba so that land fixes could be made. Fluorescein dye was also used in an effort to study the behavior of the surface layer. At this point it was decided that a quick survey of the whole area should be made with the GEK, and following a brief pause in Guantanamo Bay, 900 foot BT sections were made across the Windward Passage, the Gulf of Gonave, and Navassa Island Passage with a stop near Navassa Island to occupy another buoy station. Strong southerly currents prevailed there. Another buoy station was made toward the center of the area described above, and more soundings were taken closer to Jamaica, after which the ATLANTIS put into Kingston, Jamaica to spend Easter weekend.

The 7th found the ATLANTIS at sea again making a hydrographic station profile from Jamaica to Cuba. The following day more buoy work was done in the area west of Santiago where such work had been done before. On the 9th the ATLANTIS again went into Guantanamo Bay to unload most of the scientific crew and equipment. Mr. Bradshaw rode the ship from Guantanamo to San Juan in order to make more current measurements with the GEK near Navassa Island.

PART I

INSTRUMENTATION AND TECHNIQUES

Free Floating Drogues

Free floating drogues were employed extensively during the trip to measure surface and subsurface currents. These consisted of a drogue attached to a surface float by a given length of piano wire. The float was rigged with a mast from which brightly colored flags were flown.

Two types of drogues were used. One type was a 24 foot aviator's parachute. The other was a 3 x 4 foot sheet of tin bent along the longer dimensions to form a 120° angle (see Fig. 3a). Previous and subsequent tests showed that these tins drag stably through the water at speeds up to about 3 knots. A rough measurement showed that it had a drag coefficient of about 1.2. They were considerably easier and safer to handle over the side than Pritchard's four wing crosses (Pritchard and Burt, 1951), being flatter and having only four instead of eight sharp corners. The safety could have been further improved by rounding the corners. Their ability to nest in stowage was of great value and a decided safety factor.

The ideal free floating drogue would be one in which the surface floats and the connecting wire have no resistances in the water, so that the surface float would then be dragged through the water at the same speed as the subsurface current in which the drogue lies. This ideal is approached by using wire and surface floats with as small a cross sectional area as possible. The wire used was .040 inch music wire. (100 meters of the wire present a cross sectional area of 1.1 square feet to the current.)

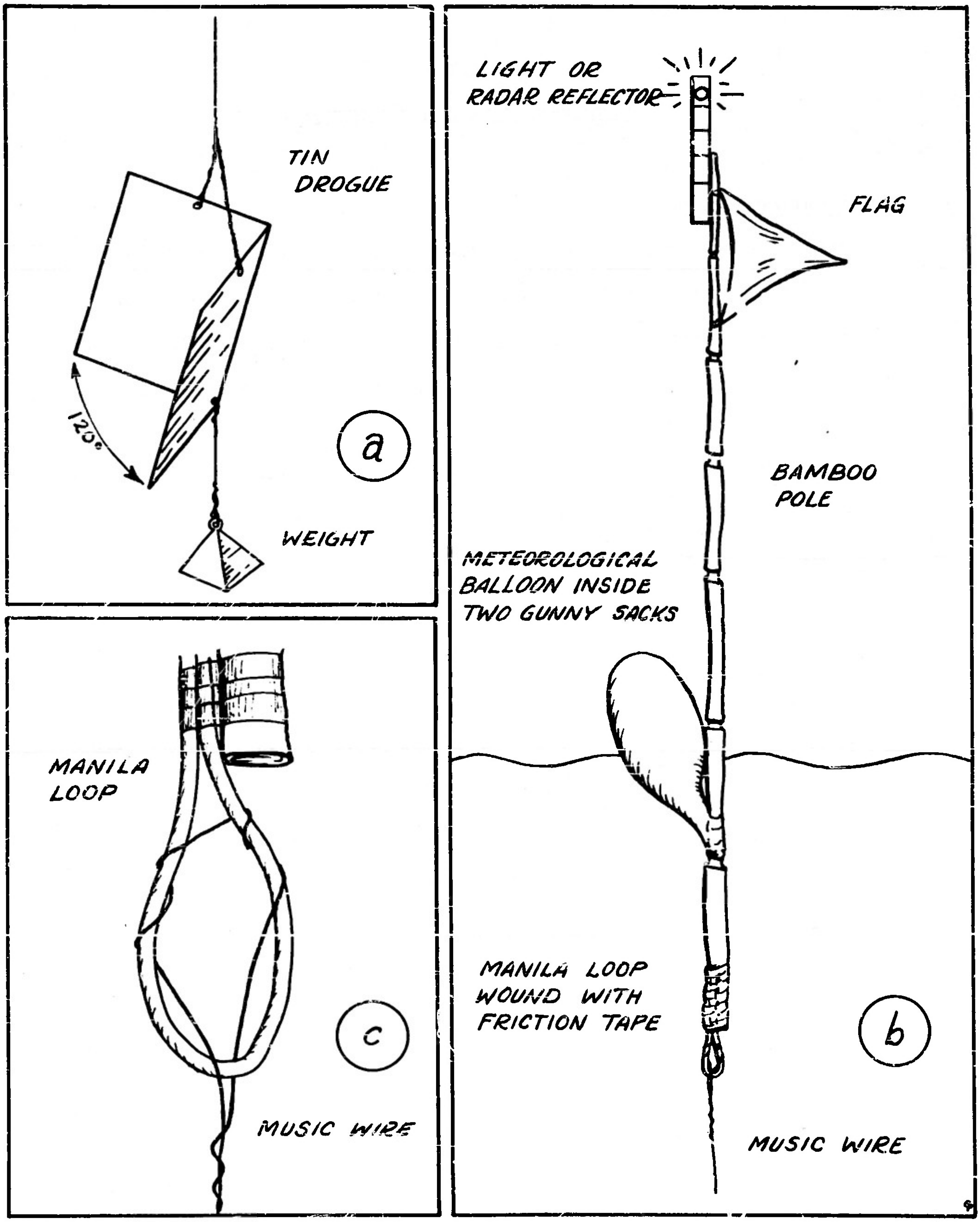

Fig. 3

Surface Floats and Drogues

The float consisted of a partially inflated meteorological balloon inside two cloth sacks which prevented chafing against the pole. While gunny sacks were used most of the time, a few more tightly woven sacks were available, and were much better. The pole mast was of bamboo about 15 to 25 feet long. One or two high visibility flags of red and yellow cloth were used to improve visual detection. The balloon floats were lashed about half-way up the pole and the weight of the music wire and drogue attached to the bottom of the pole kept it upright (see Fig. 3b). If it was planned to track the floats for a long time a radar reflector and/or light would be attached to the top of the pole. Unfortunately, the ATLANTIS radar was not performing well enough to make the radar targets worthwhile.

For measurements of currents at depths greater than two hundred meters, 24 foot aviator's parachutes were used as drogues. These parachutes had a drag area of about 30 square meters which was large compared to the area of the suspending float and wire, and hence, more nearly approached the ideal.

At first some trouble was encountered in getting the parachute over the side in the presence of wind, and in getting it set properly. The method finally evolved was to attach a weight of some 20 to 60 pounds where the drogue wire and the parachute harness met, and to lower this weight over the side first. The parachute was previously stretched out full length and then was passed over the side between the fingers of someone leaning over the rail as far as practical. In this way the parachute was unable to open until it was in the water. A logical variation of this method would be to have the parachute packed in a rubber hose some 4 inches I.D. and 15 feet long. With such a system, the harness end of the hose could be lowered into the water first and the wind would not have an opportunity to catch the parachute.

Recovering Drogues

The buoys and tin drogues were not expensive and were considered expendable. They were not a hazard to navigation and it was thought that there was a chance that we might run across them during a later part of the trip and thus gain data integrated over a longer period of time. Unfortunately no drogues were found after they had been abandoned.

Even though the parachutes were from over-age supply, (over-age parachutes can be purchased for less than twenty-five dollars apiece) attempts were made to recover them. A second larger float was rigged with a snatch block suspended beneath it. The first float attached to the parachute was then recovered and replaced on the upper end of the drogue wire by a heavy weight. The wire was then led through the snatch block, and the new float and weight thrown overboard. The heavier weight exerted a steady pull on the parachute and brought it from 700 meters to the surface (Fig. 4a) in a matter of 40 minutes. The larger drag area of the parachute kept it away from the weight and thus prevented tangling. The pole and flag of the new float made it easy to locate again.

Since the parachute remained set even when it was at the surface, it was quite a problem to bring it aboard even in calm weather. To improve the ability to recover in heavy weather a system to spill the parachute was devised as follows: The lines from the periphery of the parachute divide it into two halves and come to two separate rings; 50 foot manilla leaders were attached to each ring, and thence to the bottom of the wire. When the new float was hauled aboard the music wire was cut and allowed to sink so that no wire with strain on it was ever held by hand, the strain of the parachute now being held by the leaders. The parachute spilled as soon as the leader was cut and could easily be hauled aboard.

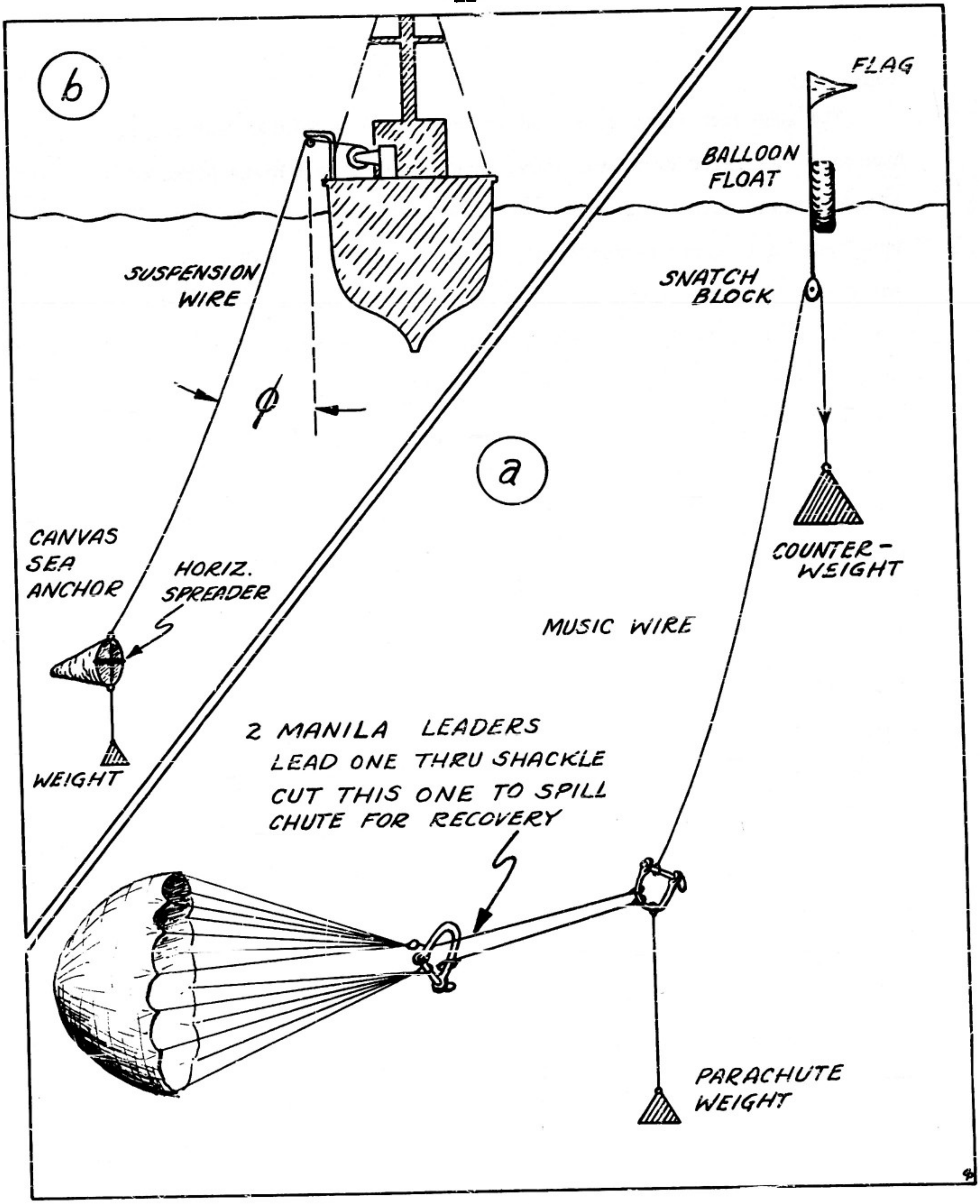

Fig. 4

Parachute Drogue and Suspended Sea Anchor

Music Wire

The .040 inch music wire used was purchased in 25,000 foot coils, placed on a tapered drum, and wound onto a reel with a brake attached. Although music wire can be obtained commercially on reels, we did not know this until after we had obtained ours in 100 pound coils. After several trials and a visit to the factory we were able to rewind the wire from the coils to the reels. Since the coil fits more or less loosely even on a proper sized drum, and therefore does not uncoil smoothly, an elastic shock cord take-up was rigged, and the coil could be unwound at a speed up to about 8 feet per second, (Fig. 5a). Once on the brake-equipped reel it could be paid out over a meter wheel in closely controllable lengths and at moderately controllable tensions, (Fig. 5b). In the future we would purchase wire on drums.

A word of caution on the use of music wire seems indicated. If even moderate amounts are to be used, improper equipment will make it extremely dangerous, and nearly impossible to use. If one is going to buy music wire in coils, a proper sized tapered drum is an important part of the equipment. Furthermore, music wire is easily rusted and this makes it hard to handle. Since it is difficult to hold on to when there is tension, it was held with the brake on the reel and a wire clamp attached outboard of the meter-wheel (Fig. 5c). The rest of the rig was then hooked to a bail on the clamp and the entire rig was released by cutting the wire between the meter-wheel and the clamp.

The problem of securing and taking tension at the end of the piano wire has received considerable attention by many users in the past. Methods and reports described by the Coast and Geodetic Survey in their

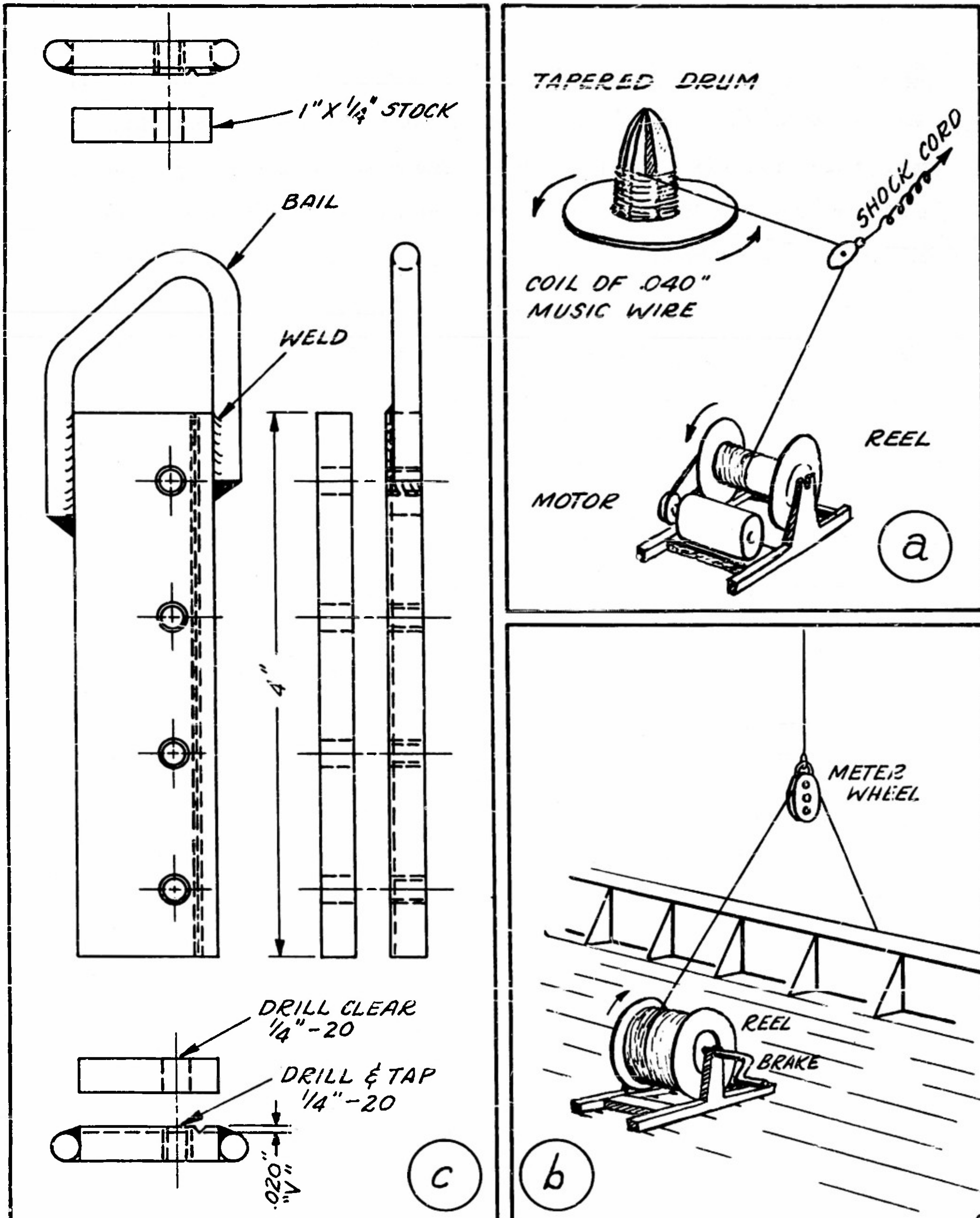

Fig. 5

Handling of Music Wire and Wire Clamp

Hydrographic Manual (Adams, 1942) were studied, and while they were tried, we evolved two other methods which were finally used. These fastening methods are shown in figures 5c and 3c. The metal clamp shown in figure 5c could be mounted on the wire before the wire was cut, and the four Allen screws could be tightened in less than half a minute. This feature was of great value when the line tension was high and increasing rapidly. Another important feature of this clamp is that the center of the becket is very nearly in line with the wire to prevent bending of the wire.

Because of a temporary shortage of metal clamps the manila loop shown in figure 3c was evolved. The line where it came into contact with the wire was thoroughly wound with friction tape and no appreciable chafing was observed during the tests. It proved to be a very effective attachment and was used on whichever end of the wire went overboard first.

Since it was desired to keep the tension on the wire to a minimum when handling it, and also to pay out wire at a reasonably fast speed, the floats for all drags over 500 meters were put over first. The ship then steamed away paying out wire over the starboard side to within 200 meters of the desired length, at which point the ship was turned 90° or more to the right and stopped. The wire clamp was then put on, the drogue was thrown overboard and allowed to sink at its leisure. This technique proved particularly useful in lowering the parachute drogues and anchored buoys.

Drogues and floats were rigged as needed. The material used was inexpensive; bamboo poles, meteorological balloons, gunny sacks, parachutes, and bent sheet tin are all reasonably compact and easily stowed, so that even a small vessel can carry the makings of one or two hundred such free floating drogues.

Calculation of Current from Drogue's Trajectory

The drogues and buoys were designed to hold their position as well as possible with respect to the water at drogue depth. By dropping several buoys at the same time, with drogues suspended at various depths, it is possible to observe the relative motion and hence the relative velocity at various depths. However, to know the absolute velocity, it is necessary to know the absolute change in position of one of the buoys and it is always best to consider the absolute velocity of the slowest one as the most critical one. Except when working close enough to shore to obtain terrestial sights, this meant depending on celestial navigation, LORAN, or an anchored buoy for position. The latter was used when out of sight of land.

As mentioned before, a very real problem in measuring subsurface currents in this way is to compensate properly for the drag on the buoy and the wire. This is important because in the usual case the subsurface current is smaller in magnitude than the surface current.

The drag on a submerged body in the water can be expressed as

$$F = \frac{1}{2} C_D \rho A v^2 \qquad (1)$$

where

C_D = non-dimensional coefficient of drag (we used 1.2)

ρ = density of water (approx. 2 slugs/cu.ft. in the English system)

A = cross sectional area of that part of the body in water

v = velocity of water relative to the body

If one considers a surface buoy and a deep drogue and neglects the drag of the cable joining them one can equate the horizontal forces acting at the top and bottom of the wire resulting in:

$$A_f C_f (\overline{V}_s - \overline{V}_d)^2 = A_d C_d (\overline{V}_d = \overline{V}_t)^2 \qquad (2)$$

where

A_f = cross sectional area of the float

A_d = cross sectional area of the drogue

C_f = drag coefficient of the float

C_d = drag coefficient of the drogue

$\overline{V}_s$ = velocity of the water at the surface

$\overline{V}_d$ = velocity of the drogue

$\overline{V}_t$ = velocity of the water at drogue depth

The simplification that the wire drag is negligible can be replaced in the two layer case by assuming that A_f represents the area of the float plus the area of the wire in the upper layer while A_d represents the sum of the area of the drogue plus the area of the wire in the lower layer. This approximation does not seem to be too bad as the drag coefficient for the floats, drogues and wire all seem to be reasonably close to 1.2 for the Reynold's numbers involved.

$$\overline{V}_t = \overline{V}_d - (\overline{V}_s - \overline{V}_d) \sqrt{\frac{A_f C_f}{A_d C_d}} \qquad (3)$$

If we let $\overline{V}_o$ be the relative velocity between the floats of a shallow drogue and a deep drogue ($\overline{V}_s - \overline{V}_d$) then the true difference of water velocity ($\overline{V}_s - \overline{V}_t$) at the two depths is

$$\overline{V}_s - \overline{V}_t = \overline{V}_o \left(1 + \sqrt{\frac{A_f C_f}{A_d C_d}}\right. \qquad (4)$$

This equation can be further applied if one thinks of the float and drag as being replaced by equivalent discs of radius r and R and if one assumes that the drag coefficient of the float and of the drag are equal.

$$\bar{V}_s - \bar{V}_t \doteq \bar{V}_c \left(1 + \frac{r}{R}\right) \qquad (5)$$

The metal drogues at depth generally were ballasted with 20 to 40 pounds in addition to their 15 pound weight. This was not deemed necessary for shallow drogues on small floats. Experiments made in a flume showed that for angles from the vertical of less than 45°, there was no serious reduction in the total drag of the drogue due to the planing action of the drogue. The reason advanced for this is that the addition of the skin friction drag compensates for any loss in effective cross sectional area and form drag.

Bottom Release Floats

Another type of float was used to make an integrated measurement of the current in a vertical section as opposed to the drag type which measures current at a specific depth. This float (Fig. 6a) was set over the side with a detachable weight sufficient to sink it, and when it reached the bottom the weight was released, and the float with its pole and marker flag rose to the surface. The ballast was held by a ring which hung on a sloping pin. When the ballast struck bottom the overshoot of the float would result in a slackening of the ballast line and a preloaded flat spring threw the ring and hence ballast clear. The floats were based on earlier work done by Ewing and Vine (1938). In order to reduce the fire hazard aboard ship, paraffin having a specific gravity of 0.91 was used in the floats instead of aviation gasoline having its specific gravity of 0.72. The reduced buoyancy of the paraffin was somewhat offset by not requiring the added weight of a tight case.

The proper procedure was to release the float or floats near an anchored or surface float, and then stand by the surface float and note the

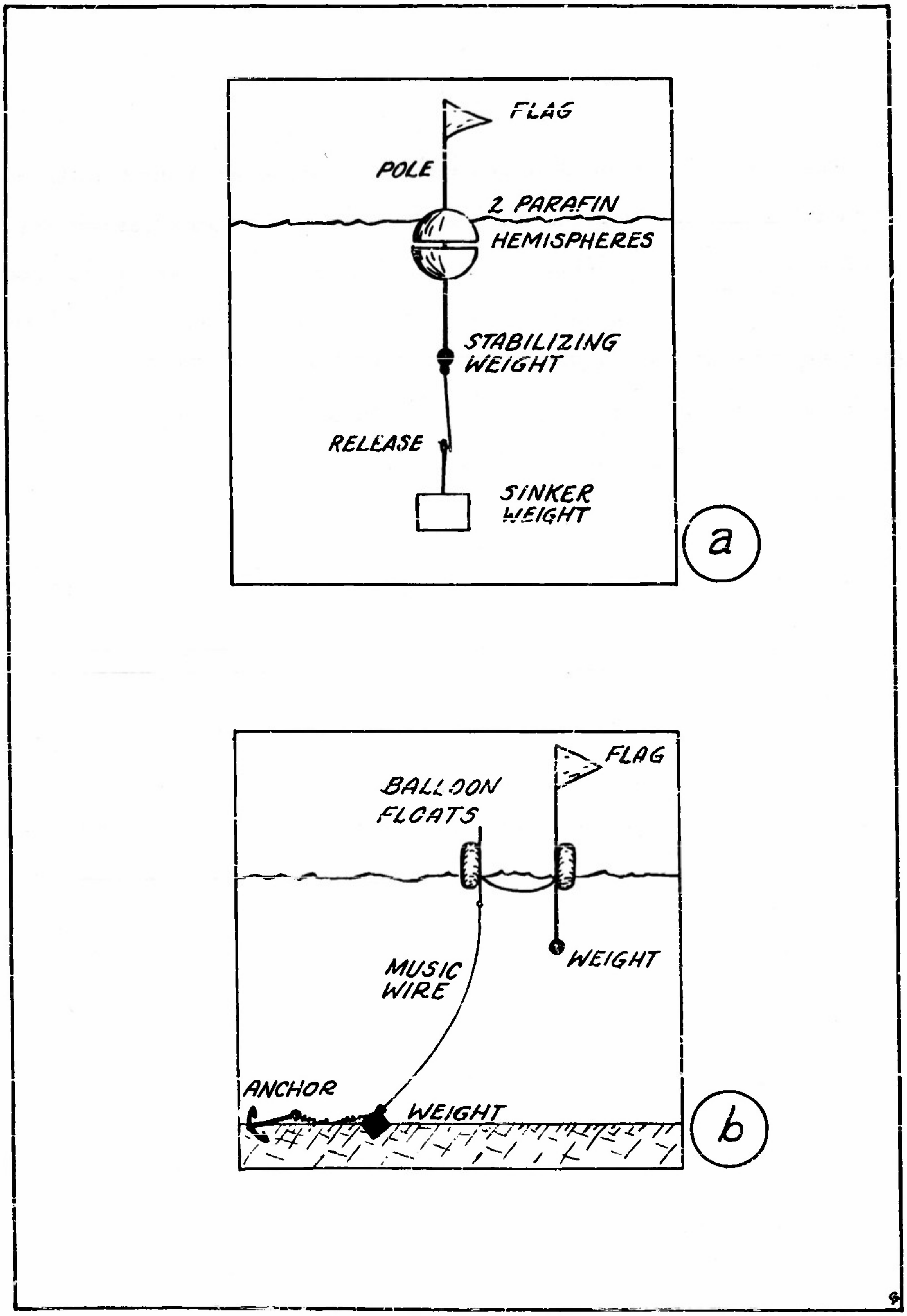

Fig. 6

Release Buoy and Anchored Buoy

range and bearing at which the release float surfaced. These numbers coupled with the time which the buoy was down will give the velocity of the relative current averaged over the depth reached. These floats were very useful in making a quick qualitative determination of vertical shear.

When release floats were used it was customary to set one with a soluble salt release device so it would be down for about 20 minutes, and another that would go to the bottom before it released. The latter took somewhat over an hour for the round trip in 2000 fathoms. Time did not permit as much use of these floats as had been hoped for.

Anchored Floats

An anchored float (Fig. 6b) was used several times on the cruise with varying degrees of success. The buoy itself was a somewhat more rugged version of the buoy used in the free floating drogue work. It was anchored to the bottom by means of .050 inch piano wire using about 75 pounds of scrap iron and a twenty pound stock anchor modified slightly by the addition of larger flukes. In practice, the anchored buoy was dropped first, then surface and subsurface drogues were released next to the anchor buoy.

The accuracy of trajectory measurements made of surface and subsurface drogues from an anchor buoy is dependent upon the yaw of the anchored buoy, and hence, on the scope of the wire. One can estimate the probable yaw of the anchored buoy and conclusions from the observations should not be made until the free floating drogues have drifted considerably further than this yaw. It is obviously important to have the anchored buoy reach an equilibrium position after being laid before accurate trajectory measurements can be made from it.

Most of the work had been planned around anchored buoys, but in actual practice they were only used four times. The reason was that the currents encountered were so large that a scope of 1.4 times water depth was required in order that the float would not be pulled under. It was, therefore, theoretically possible in two miles of water and in the presence of shifting currents for the surfaced buoy to be anywhere within a circle 4 miles in diameter. In actual practice the control was much better than this. For example, if the current remains at about the same strength and in about the same direction, the surface buoy will remain in a given sector from, and about at the same range, from, the anchor. This could be easily checked periodically by releasing a release float. This meant that an experiment had to run for some time to obtain high precision, and unfortunately, the ATLANTIS was not fast enough to keep herd over a group of free buoys and still keep returning to the anchored buoys.

Flag Codes

Much of the time several different kinds of buoys were being followed at once. In order to keep track of the buoys with a minimum of confusion, it was essential to have a different flag combination on each buoy. In addition, it was desired to keep the flags as small as possible to reduce windage. The flags chosen were a special yellow and red cloth* of exceedingly bright hue and distinguishable from each other at about 75% of maximum visibility. The flag combinations used are shown in Fig. 7. Each type of buoy had one distinguishable feature to identify its class. The authors strongly advise that all reasonable aids to identification should be employed in any buoy tests.

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* Sold by M. Hausman and Sons of New York.

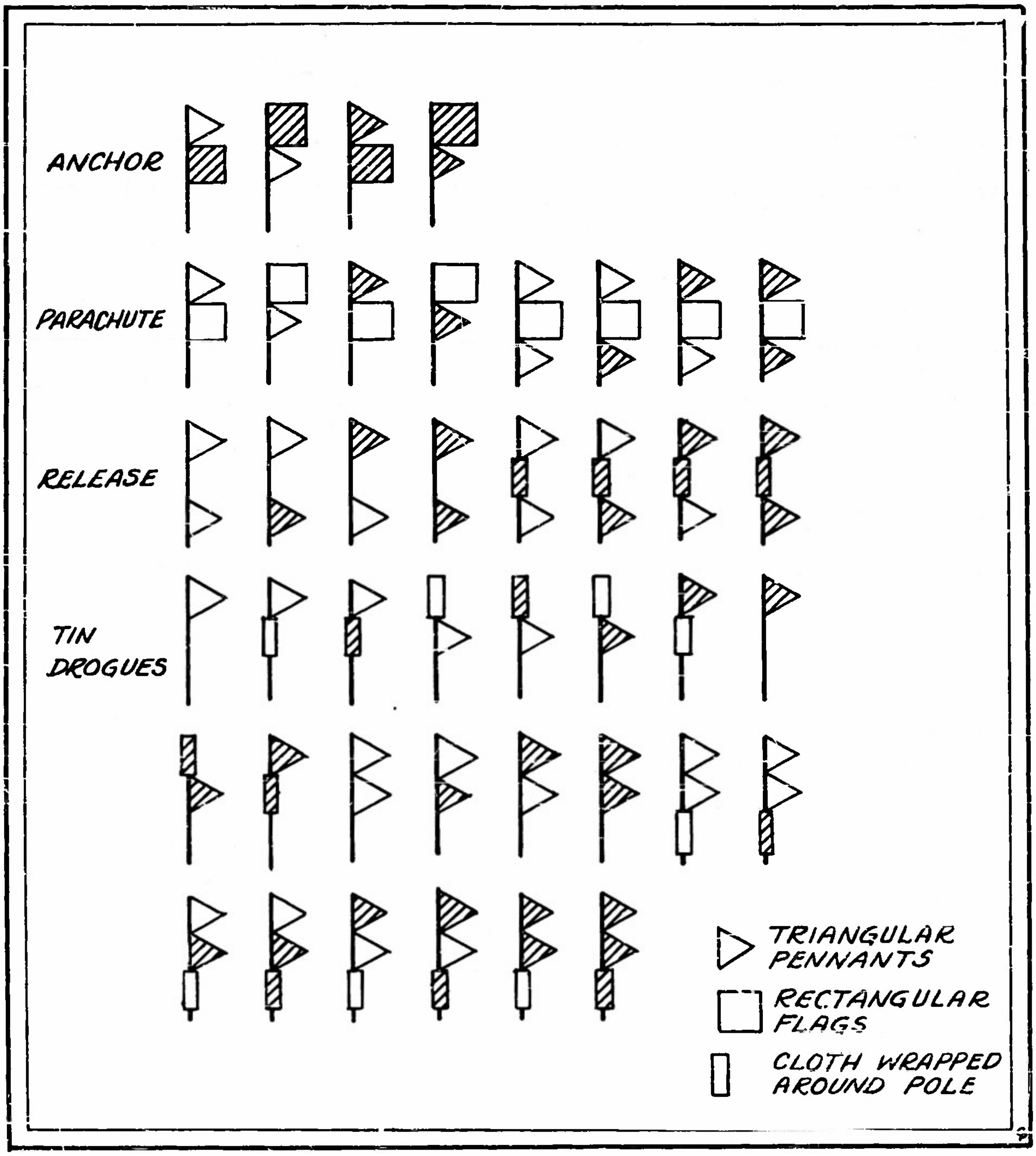

Fig. 7

Two Color Flag Code

Dye Marker

Several attempts were made to see if there was any small scale streakiness or convergence in the surface currents by using fluorescein dye marker.* Attempts were also made to see if there was any appreciable current shear in the top ten meters by using dye marker next to "surface" drogues.

In three cases there was no observable shear in the surface 10 meters, and it was believed we could have detected a shear as great as .04 knots. In a fourth case a shear in the surface 10 meters of 0.2 knots was observed. In a prevailing southerly current the water at 10 meters was moving south faster than the surface water. This was in presence of a Force 3 easterly wind.

In no case was extreme streakiness apparent. In only one case did the dye spot become as long as three times its width. Experience has led us to make a number of comments concerning the use of fluorescein dye.

First: It is absolutely insidious in its ability to permeate clothes and the ship. The utmost care in handling it as a powder is essential. As a liquid it becomes only slightly less dangerous as a corrupter of ship's morale. In practice, we put a man over the side on the hydrographic platform where he would put several pounds of powder into a 10 gallon plastic bottle.

Second: The useful life of the dye for experimental work seemed to be limited to about an hour.

Third: The particular dye used did not seem to stay at the surface; hence shear in the top one or two meters is rather difficult to measure.

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* This dye is available from the New York Color and Chemical Co., Belleville, New Jersey, at about $3.00 per pound.

GEK

The GEK has been described by its inventor, von Arx (1950). The principle of the GEK is based on the fact that salt water moving through the earth's magnetic field will set up potential differences within itself. Various relationships between ocean currents and the electrical potential measured by the GEK have been discussed by Stommel (1948), and Malkus and Stern (1953). It is the belief of Knauss, who has made extensive measurements with the instrument on the West Coast, that in deep water the GEK measures surface currents correctly, under most circumstances, to within twenty per cent. Conditions which give spurious results on the GEK, (surface currents which extend to a significant fraction of the depth of the water, reversals of current with depth, or strong horizontal current gradients) were not often encountered. GEK observations were frequently checked with other means of measuring and estimating surface currents.

For comparison purposes, the GEK was used both with and without floats. When floats were not used, a correction was made for the fact that the cable was not towing horizontally. It was assumed that with a ship's speed of seven and a half knots that the far electrode was towing six and a half meters deeper than the near electrode. This figure was arrived at on the basis of measurements made on the Shellback Expedition of the Scripps Institution of Oceanography, (Wooster, 1952). No systematic difference could be found in the GEK measurements made when the GEK was towed with floats, or when towed without floats, and the correction for "cable droop" applied.

One reason for not using floats on the GEK cable is because if there is a heavy wind, it might be expected that floats and cable would be affected by windage. If this happened a calculation of the current would include as a systematic error, a false current whose direction is the same as the wind and whose magnitude is proportional to the windage.

GEK LIST

Station No.	Date 1953	Time	True Current Velocity cm/sec	True Current Direction degrees
1	17 March	1040	60	093
2		1300	37	033
3		1500	16	321
4		1600	33	279
5		1700	23	327
6		1800	57	275
7		1900	41	254
8	23 March	0845	14	060
9		1015	25	043
10		1145	11	020
11		1315	20	294
12		1445	14	002
13		1615	16	337
14		1930	35	085
15		2100	23	068
16		2230	35	033
17		2400	23	043
18	24 March	0130	31	067
19		0300	33	073
20		0430	40	080
21		0600	32	105
22		0730	27	131
23		0900	38	111
24		1020	29	137
25		1200	39	130
26		1330	33	161
27		1500	38	109
28		1630	35	070
29		1800	45	057
30		1930	38	020
31		2100	22	059
32		2230	22	088
33		2400	33	112
34	25 March	0100	34	94
35		0240	32	87
36		2300	70	112
37	26 March	0030	70	113
38		0200	55	126
39		0330	54	138
40		0500	60	142
41		0630	63	143
42	28 March	1230	22	183
43		1345	66	148
44		1530	44	171
45		1930	66	175

GEK LIST
(continued)

Station No.	Date	Time	True Current Velocity cm/sec	True Current Direction degrees
46	29 March	0600	65	170
47		0730	53	159
48		0900	56	140
49		1030	38	174
50		1200	45	198
51		2300	15	347
52	30 March	0030	27	326
53		0100	28	325
54		0300	32	322
55		0430	17	045
56		0600	29	124
57		0730	49	109
58		0900	11	105
59		0930	11	195
60		1030	16	289
61		1200	4	285
62		1330	32	205
63		1455	23	185
64		1600	24	161
65		1730	44	204
66		2008	16	243
67		2135	35	248
68		2300	38	016
69	31 March	0030	40	094
70		0200	41	112
71		0330	21	082
72		0500	32	159
73		0625	70	150
74		0830	83	175
75		2000	53	155
76		2130	41	146
77		2300	43	204
78	1 April	0130	41	223
79		0200	32	227
80		0330	15	245
81		0500	23	278
82		0640	26	199
83		1200	20	190
84		1330	20	168
85		1500	21	182
86		1630	17	225
87		1800	15	321
88		1930	16	292
89	2 April	2200	14	106
90		2330	11	106

GEK LIST
(Continued)

Station No.	Date 1953	Time	True Current Velocity cm/sec		True Current Direction degrees
91	3 April	0100	35		155
92		0235	14		267
93		0400	12		150
94		0600	8		130
95		0730	4		105
96		0900	34		279
97		1100	21		333
98		1300	25		232
99	6 April	1930	82		295
100		2115	89		220
101		2300	52		263
102	7 April	0025	34		072
103		0615	11		161
104		0750	9		031
105		0945	111		344
106		1310	50		352
107		1430	50		312
108		1530	64		299
109		1930	56		288
110		2110	46		295
111		2200	-	No data	-
112		2245	-	No data	-
113	8 April	0230	25		272
114		0330	21		300
115		0430	36		068
116		2200	-	No data	-
117		2330	-	No data	-
118	9 April	0100	29		088
119		0230	80		084
120		0400	94		093
121		0445	42		095
122		(1200)	17		288
1'	11 April	2100	21		254
2'	12 April	0050	13		131
3'		0215	24		257
4'		0530	60		178
5'		0910	40		040
6'		1115	37		224
7'		1315	105		199
8'		1650	88		190
9'		1900	49		308
10'	13 April	0130	47		350
11'	14 April	2330	-	No data	-
12'	15 April	0230	30		121
13'		0600	29		031

On several occasions when the wind was Force 4 or greater, the cable was changed from one with floats to one without floats, and successive GEK's were compared. Since no two GEK's taken an hour apart can be expected to agree absolutely, this method of checking is not ideal. However, no systematic difference was apparent, and it is tentatively concluded that windage is not an important factor with floated GEK cables.

Suspended Sea Anchor

Pritchard and Burt (1951) have described a method of computing the velocity structure from measurements of the vertical and horizontal angles subtended by a weighted sea anchor lowered to various depths from an anchored ship. They have used this method extensively in water depths up to 100 feet deep. With water this shallow, the effect of wire curvature and the drag and weight of the wire are small enough so that they may be neglected. This means that the vertical angle made by the wire is determined entirely by the forces acting on the sea anchor.

$$\tan \phi = F/W \qquad (5)$$

where ϕ is the angle from the vertical, W is the weight of the sea anchor in water, and F is the horizontal force on the sea anchor caused by the flow of water by it.

$$F = \frac{1}{2} C_D \rho A v^2 \qquad (6)$$

C_D is the drag coefficient, ρ, the density of water, A, the cross sectional area, and v, the velocity of water.

An attempt was made on this cruise to use this method from a floating ship to measure vertical shear. When this is done, the velocity in Eq. (6)

is the relative velocity between that of the ship and the water at the depth of the sea anchor.

The interpretation of such measurements involves several assumptions. In the first place, the rate of drift of the ship is in general not identical with the surface velocity. This has been allowed for by rather arbitrarily saying that the surface velocity is constant to a depth of 10 meters, and that any apparent current shown by the sea anchor at this depth is caused by windage on the ship.

Another problem is that below a certain depth (in our case we estimated 100 meters), it is no longer possible to assume that the area of the wire is a negligible factor. It is necessary to correct for both the curvature of the wire and the forces acting on the wire. The technique is complicated but no more so than many problems involving step by step integration.

For example: We can usually measure the relative velocity structure to a depth of 100 meters without applying any correction for the wire. For the observation at a greater depth, say 125 meters, we can solve for the curvature and forces acting on the wire, since we have previously measured the velocity to 100 meters. And finally, we may solve for the new unknown, the velocity at 125 meters. Then, with this velocity known, we can now solve for the velocity at the sea anchor when it is lowered to 150 meters, and so on. The actual computations in this stepwise integration are fairly simple and require about an hour's calculation for a series of ten or twelve depths.

The sea anchor which was used was a standard three foot diameter canvas sea anchor, with the suspension wire attached to the top of the opening and the weight attached to the bottom of the opening with a horizontal spreader holding it open sideways (Fig. 4b). The amount of weight attached was determined by the shear that

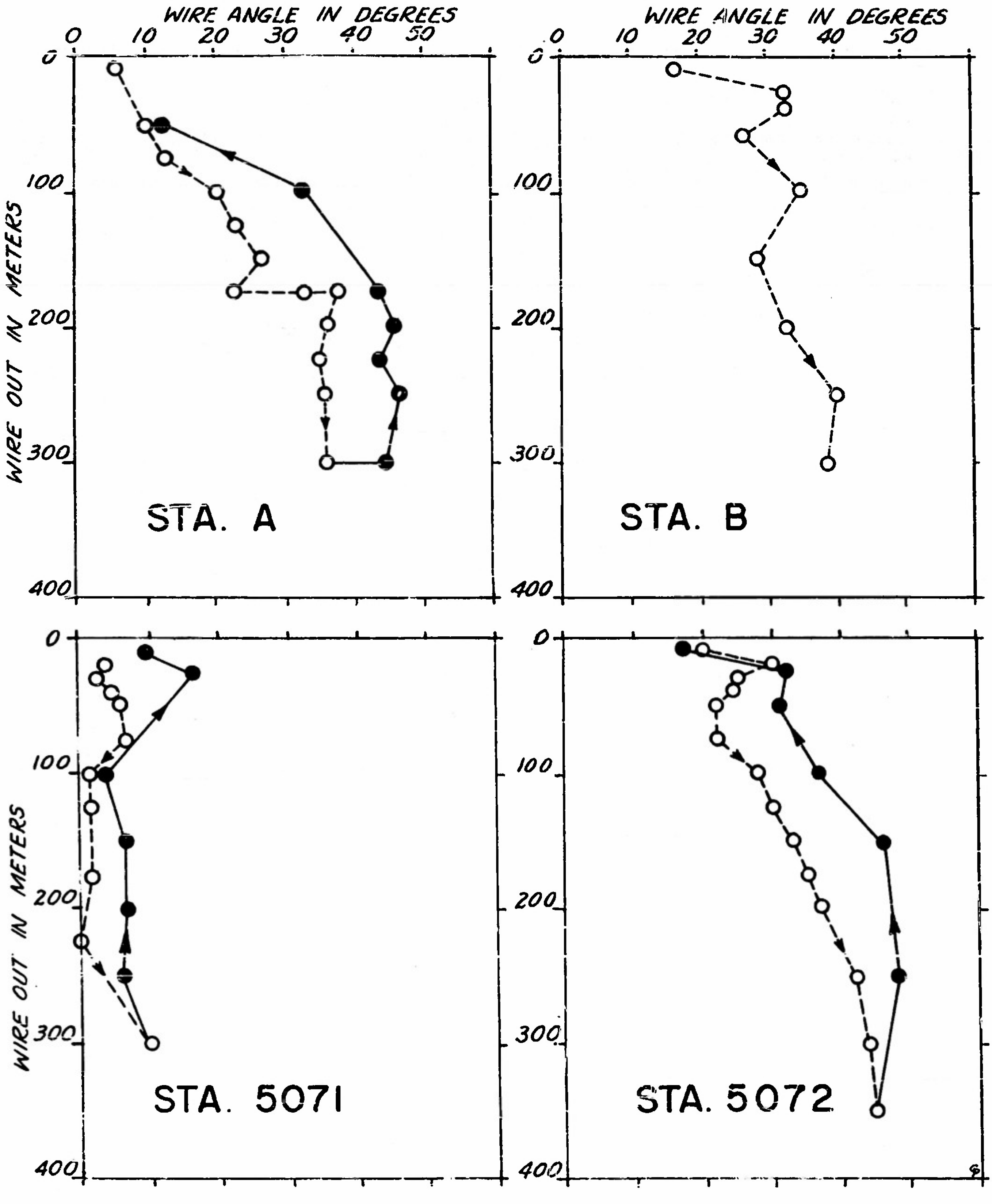

Fig. 8

Suspended Sea Anchor Measurements

was expected and was usually about 60 pounds. It was lowered from the hydrographic winch on 3/16 inch wire.

In some respects this method of measuring current shear was very successful. For example, when the vertical shear was negligible there was no quicker way of finding it out. The precision possible with a given wire and sea anchor will fall off with depth. For the combination used, it was believed to be accurate down to 300 meters to 0.1 knot, or 40% of the total shear, whichever is greater.

One reason this method was not more accurate was that there was a systematic difference in readings made at the same depths when the sea anchor was being retrieved and when it was being lowered. Readings made while retrieving the sea anchor were consistently higher than those made while lowering (Fig. 8). It was not a question of waiting for the suspended anchor to reach equilibrium. On occasion, a wait of a half hour to forty five minutes was made and still the difference persisted. This inconsistency had also been observed earlier by Vine. We have no explanation for this systematic hysteresis loop, either in terms of hydrodynamics, operational errors, or omissions.

THE CURRENTS OF THE EASTERN CAYMAN SEA

PART II

As mentioned in Part I, the original purpose of this cruise was to test and compare different techniques for measuring currents in the open ocean. However, almost immediately it was discovered that the current system was so different from what had originally been reported for this area, that the emphasis of the cruise was changed from one of comparing techniques to that of deciding what was happening.

Current Structure 17 March - 1 April

Available information for this area, (Parr, 1936, Dietrick, 1939) suggest a weak current structure with general flow to the west, (Fig. 19). This was not what was found. What was observed during the first half of the cruise can be seen from figure 9. There was a strong coherent surface current of about a knot running eastward between Jamaica and Cuba, then turning, picking up speed, and rushing south through the area between Haiti and Jamaica. Furthermore, this was not just a surface current. Subsurface currents were measured by free floating drogues at two stations A and B shown in figure 9, and are plotted in figures 10 and 11. The calculation for these figures are given in the next two sections.

In addition current profiles were measured by means of the suspended sea anchor at both station A and B. Plots of the angles subtended by the wire are shown in figure 8. Estimates of the shear shown by these measurements tended to verify the observations of subsurface currents made by the subsurface drogues.

The GEK sections of figure 9 and the vertical velocity profiles of figures 10 and 11 indicated that there was a considerable transport of water

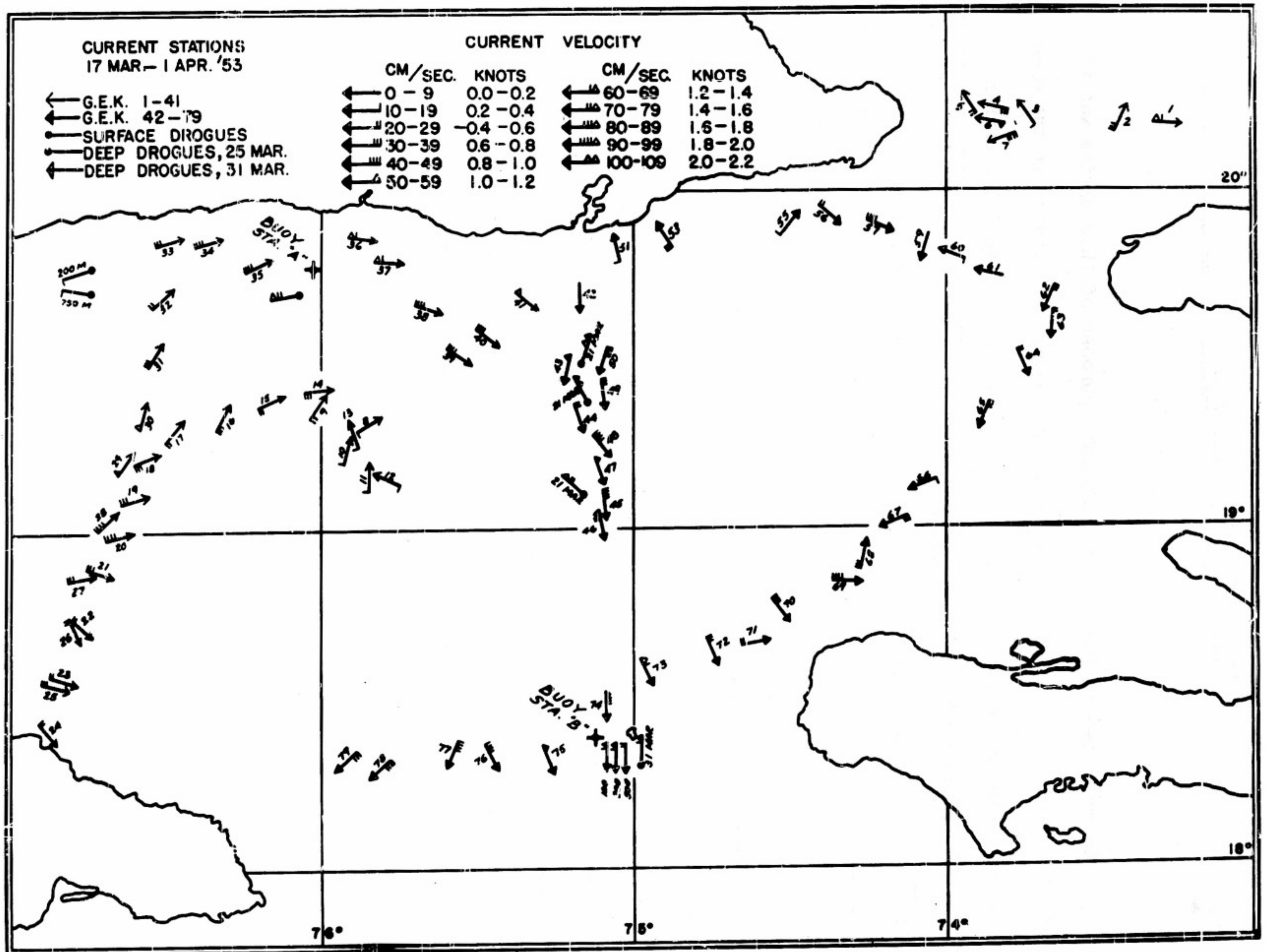

Fig. 9

Surface Currents, 17 March to 1 April

involved, and an attempt was made to estimate its magnitude.

Transport Computations for Navassa Island Passage

On the 31st of March a series of current measurements were made at station B (Fig. 9) near Navassa Island with four surface and subsurface drogues. Pertinent features of the experimental data are given in the table below. The drogue area and weight of the first three was 12 sq. ft. and 35 pounds. The 500 meter drogue had an area and weight of 450 sq. ft. and 70 pounds.

Table I

Drogue Depth	Trajectory
5 meters	2.2 miles in 121 min. or 1.1 knot 175° T
	4.5 miles in 237 min. or 1.1 knot 181° T
100 meters	2.7 miles in 132 min. or 1.2 knot 172° T
	4 miles in 215 min. or 1.1 knot 178° T
200 meters	2.15 miles in 104 min. or 1.2 knot 178° T
	4.5 miles in 232 min. or 1.2 knot 176° T
500 meters	.85 miles in 95 min. or .65 knot 178° T
	1.84 miles in 174 min. or .64 knot 183° T

The drift of the buoys was very well determined because we were operating to the west of Navassa Island and had excellent sights on Navassa light house essentially at right angles to the buoy set. As the 100, and 200 meter drogues gave essentially the same current as the 5 meter drogue; there were no corrections to be applied to them. However, the drogue at 500 meters was only moving over the bottom at 55% of the velocity of the surface float so a considerable negative correction needs to be applied.

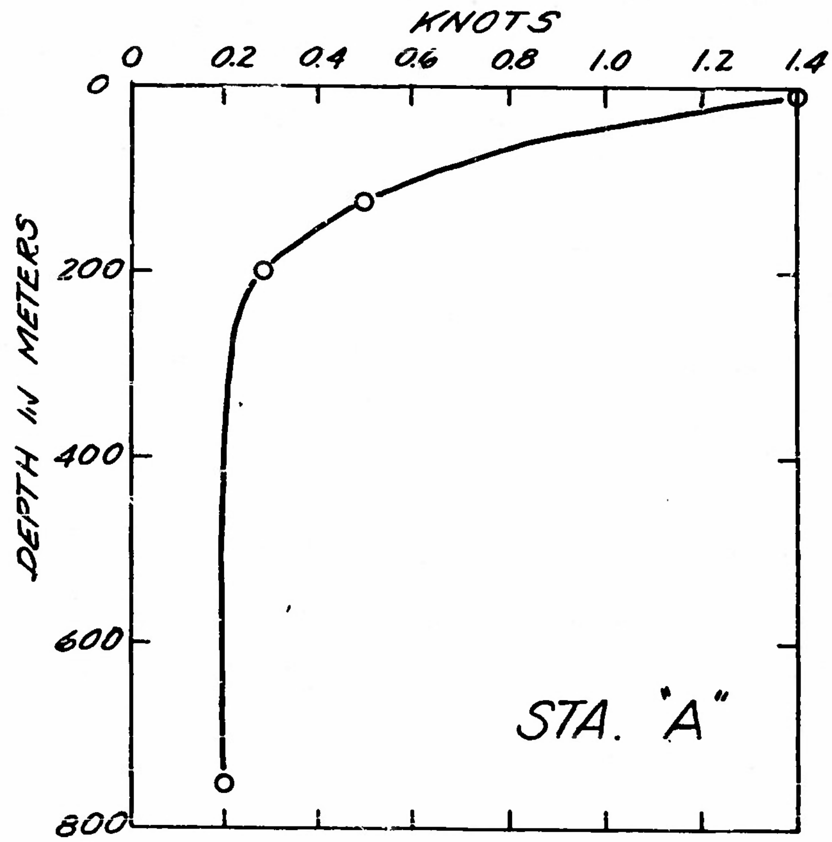

Fig. 10

Velocity-Depth Curve - Station A

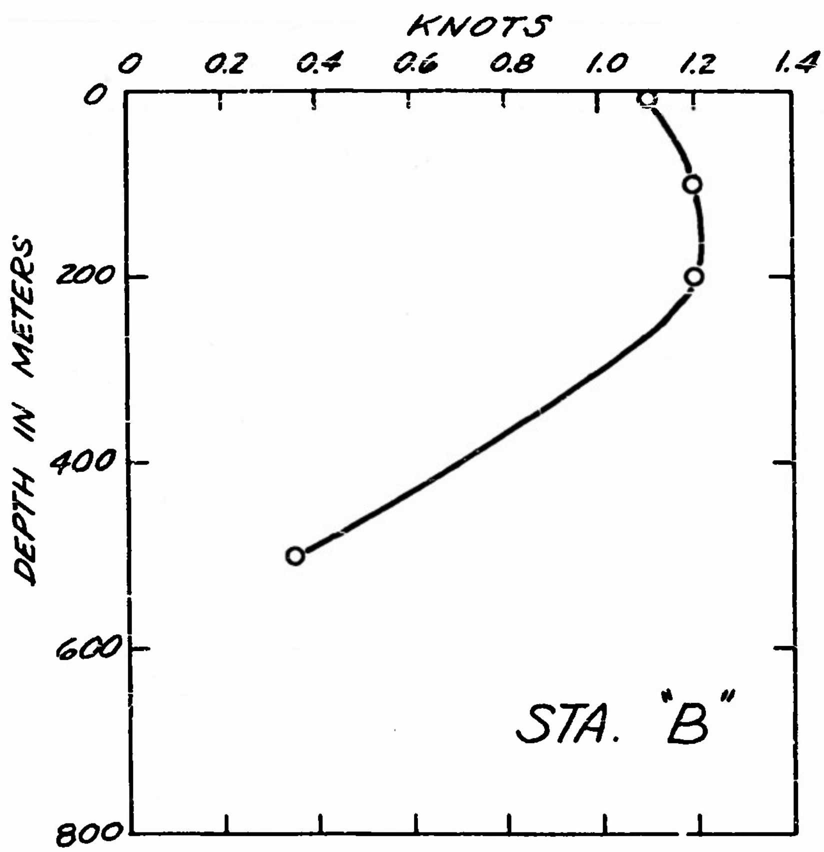

Fig. 11

Velocity-Depth Curve - Station B

The cross sectional area of the wire is about 1 sq. ft. per 100 meters of wire. So if we assume half the wire to be in the upper zone and half to be in the lower zone the effective areas of the float and drogue should be increased from 2 sq. ft. and 24 sq. ft. to 5 and 27 sq. ft. respectively. Then using Equation (5)

$$V_t = V_d - (V_s - V_d) \sqrt{\frac{A_f}{A_d}}$$

$$= .6 - (1.2 - 0.6) \sqrt{\frac{5}{27}}$$

$$= .35 \text{ knots or } 18 \text{ cm/sec}$$

Table II

Depth meters	Corrected Drift knots
5	1.1
100	1.2
200	1.2
500	.35

The values in Table II are plotted in figure 11 and a calculation was made of the transport through a unit kilometer of channel. For the upper 250 meters:

$$T_{0-250} = .60 \times 250 \times 1000 = .15 \times 10^6 \text{ cubic meters/sec/km}$$

Between the 250 and 500 meter haul

$$T_{250-500} = .37 \times 250 \times 1000 = .091 \times 10^6 \text{ cubic meters/sec/km}$$

$$T_{0-500} = (.15 + .091) \times 10^6 = .24 \times 10^6 \text{ cubic meters/sec/km}$$

The surface current values indicated by the GEK were used as a guide in estimating the transport through the entire channel.

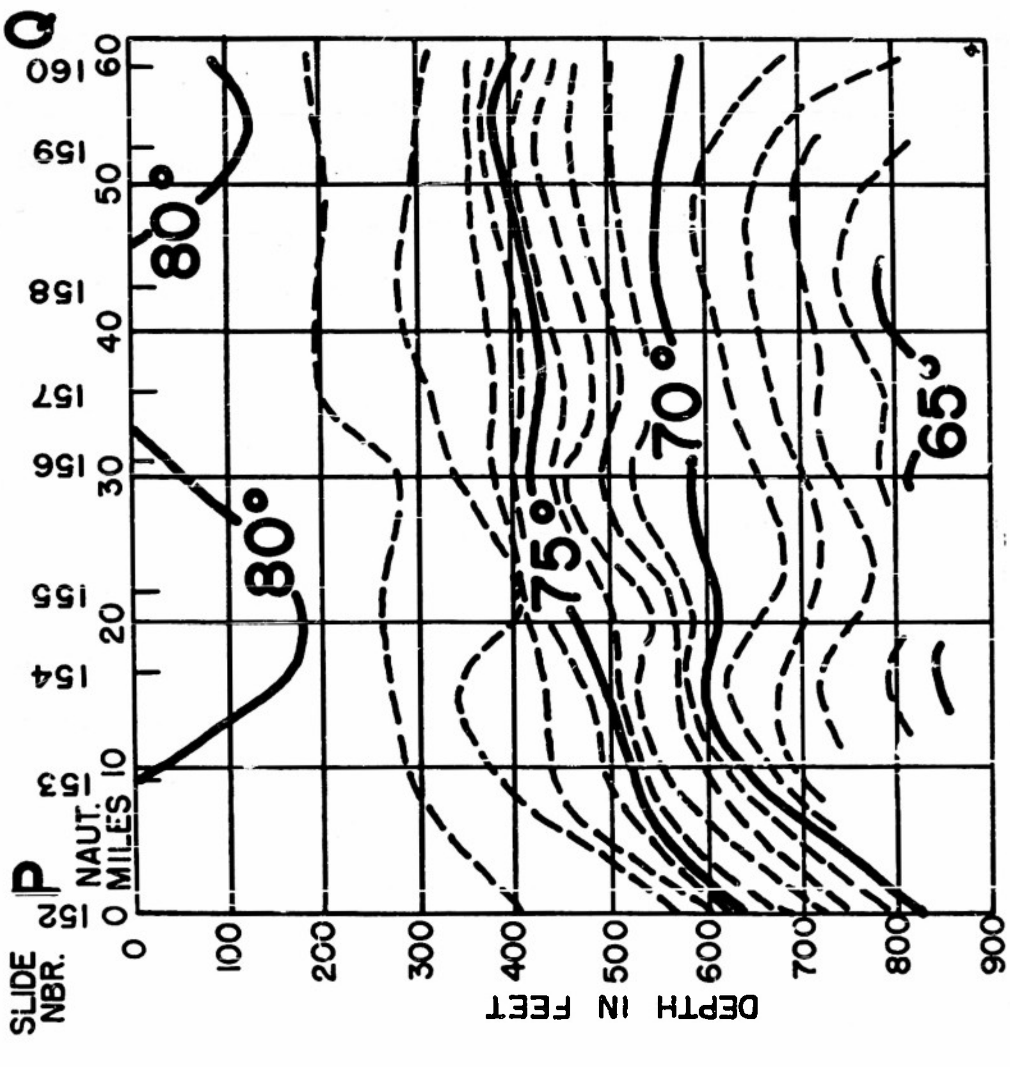

Fig. 12

First BT Profile, Jamaica to Cuba 24 March

Transport computation were made between GEK station 70 and 79 in figure 9 which is roughly line NO in figure 2. The southerly components of the GEK values perpendicular to the ship's track were computed to be somewhat over 35 cm/sec (0.7 knots). Although the channel is about 200 km wide at the surface, we considered the portion over which we made measurements and which was effectively 500 meters deep; this was 140 km.

It should be noted that GEK observations 74 and 75 made just before and after the drogue measurements show a difference of two thirds of a knot and an average velocity somewhat greater than that measured by the surface drogue. However, the sea anchor measurements made at the time of the drogue observations showed an increase in the velocity down to 50 meters corresponding to an absolute velocity of 1.6 knots or approximately that shown by GEK 74. This would seem to indicate that the velocity profile plotted in figure 11, which is taken entirely from drogue measurements, could be considered a minimum value profile. We compute the southerly transport by assuming that the ratio of average transport, to that measured, is in the same proportion as the ratio of average southerly component of GEK velocity to that of the surface velocity measured by the surface drogues.

$$T_{0-250} = \frac{35}{58} \times .15 \times 10^6 \times 140 = 13 \times 10^6 \text{ cu meters/sec}$$

$$T_{0-500} = \frac{35}{58} \times .24 \times 10^6 \times 140 = 21 \times 10^6 \text{ cu meters/sec}$$

Dynamic computations assuming a perfect temperature-salinity correlation were made from the BT profile of the Navassa Island Passage (Fig. 13). The slope of the isotherms was most pronounced on the Haiti side of the channel so the two halves of the channel were calculated separately. Since the bathythermograph data only went to 900 feet we assumed a level surface at 250 meters.

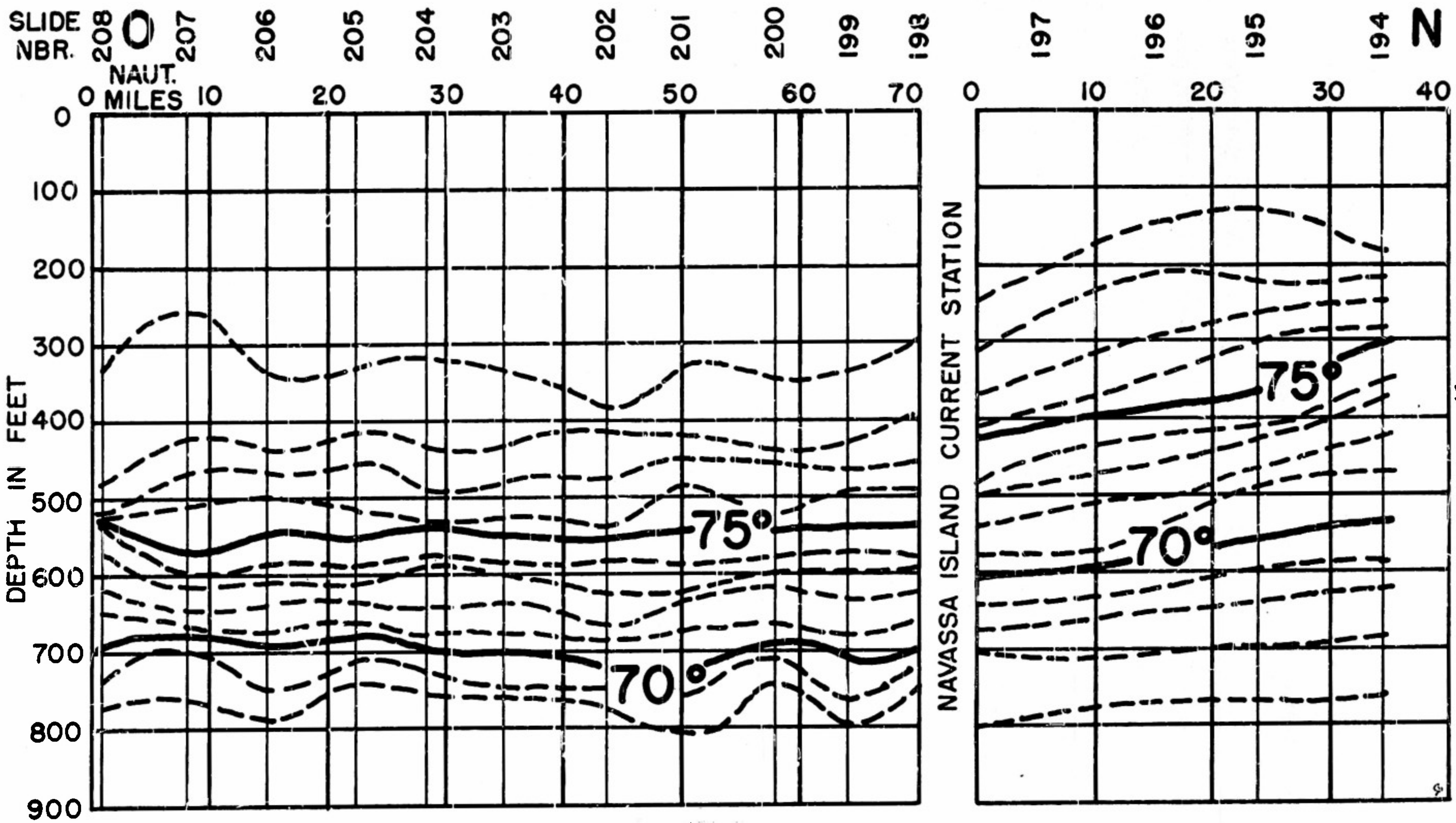

Fig. 13

BT Profile, Navassa Passage

When the flow is calculated in the above manner it is seen to be largely in the eastern half of the channel, i.e.,

eastern half	4.1×10^6 cu meters/sec
western half	$.5 \times 10^6$ cu meters/sec
entire channel	4.6×10^6 cu meters/sec

The three to one discrepancy between the dynamic computations and the drogue measurement is a large one, particularly in view of the fact that the transport as computed for the drogues was so large. We have, however, no reason to suspect that the drogue measurements are too high. It may be that even in spite of the GEK observations that the 35/55 ratio of the flow measured near Navassa Island is too large to use as an average for the 140 kilometer width.

We arrived in the area at about 0600 and left at about 1700 having noted a strong southerly set from the drift of the ship throughout the entire period with no apparent tide component. The drogue measurement, however, extended over a period of only six hours so that it is possible but not probable that the 0.35 knot current at 500 meters might have had an appreciable tidal component. Even if we allow for a 0.35 knot tidal current which would bring the level of no motion up to 300 meters the total transport would only have been reduced to about half or 10×10^6 cu meters/sec.

Transport Computations between Jamaica and Cuba, March 25

The drogue data shows 70 cm/sec at the surface, 28 cm/sec at 200 meters and 17 cm/sec at 750 meters. The drogue measurements were made by sighting on mountains on the Cuban coast. We considered the velocity of the 5 meter drogue to be surface velocity. In order to correct for the 200 meter and 750 meter drogues Eq. (3) is used. The wire used has a cross sectional area of about 1 sq. ft. per 100 meters. If we use the surface current to compute the drag on the upper 100 meters of wire and the current at 200 meters for the lower 100 meters the area of the float becomes about 3 sq. ft. and of the two tin drogues 25 sq. ft.

$$V_t = V_d - (V_s - V_d) \sqrt{\frac{A_f}{A_d}} = 28 - (70 - 28) \sqrt{\frac{3}{25}} = +14 \text{ cm/sec}$$

For the parachute at 750 meters Eq. (3) becomes,

$$V_t = 17 - (70 - 17) \sqrt{\frac{2+3}{300+4}} = 10 \text{ cm/sec}$$

resulting in a vertical distribution as determined from buoys.

5 M	70 cm/sec	towards	080° T
200 M	14 cm/sec	"	075° T
750 M	10 cm/sec	"	100° T

This data is plotted in figure 10 and from it a calculation was made in the same manner as before of the transport through a unit kilometer of channel

$$T_{0-250} = .30 \times 250 \times 1000 = .075 \times 10^6 \text{ cubic meters/sec/km}$$

$$T_{250-750} = .1 \times 500 \times 1000 = .05 \times 10^6 \text{ cubic meters/sec/km}$$

$$T_{0-750} = (.075 + .05) \times 10^6 = .125 \times 10^6 \text{ cubic meters/sec/km}$$

It is significant to note that the GEK observations 35 and 36 taken just before and after the buoy station showed a mean value of 53 cm/sec as compared to a value of 70 cm/sec given by the five meter drogue. The components of GEK observations at right angles to the 170 km line PQ (Fig. 2 and Fig. 9) gave an average value of 24 cm/sec or slightly over 40% of the GEK values taken at the time and place of the buoy measurement.

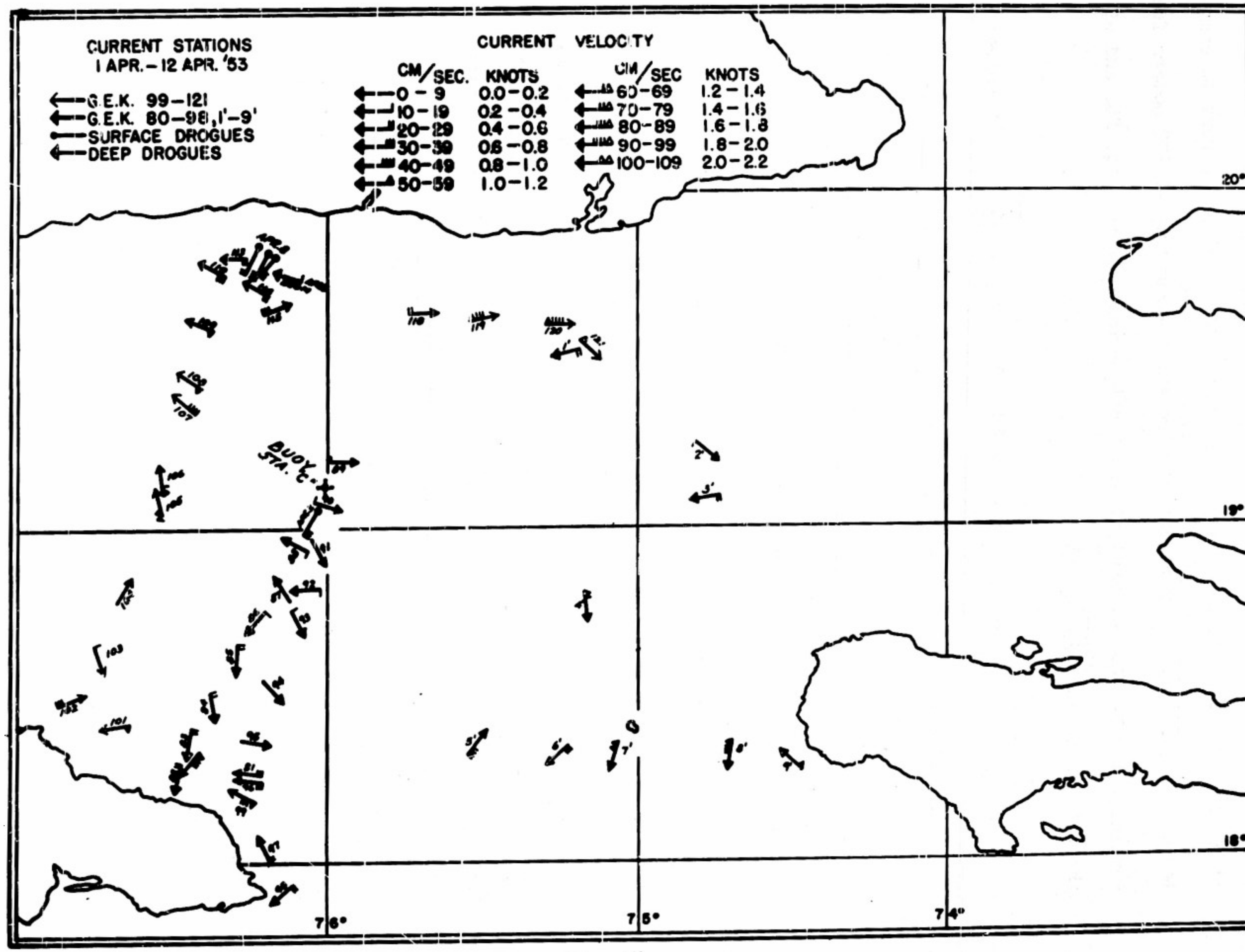

Fig. 14

Surface Currents 1 to 12 April

Following the same reasoning as that made in the Navassa Island calculation we compute the transport across line PQ to be

$$T_{0-750} = .40 \times .125 \times 10^6 \times 170 = 8 \times 10^6 \text{ cubic meters/sec}$$

Current Structure, April 1-12

Figure 14 shows the GEK observations made between 1 and 12 April. As is readily evident, the strong eastward flow was almost stopped. This is confirmed by the fact that the isotherms are almost horizontal between Jamaica and Cuba 7 and 8 April, (Fig. 15).

The only temperature-salinity section of the cruise was made on this leg, and is shown in figure 16. The calculated volume transport above the 2000 meter level was 2.3×10^6 cubic meters per second to the east. This section compares roughly with that of Parr's, made in 1934, (Fig. 17).

The question of why, and how this flow suddenly stopped, is as puzzling as what started it in the first place. Another sea anchor station on 2 April, the position of which is shown in figure 14, was taken at Station C. The surface current both by GEK and surface drogue, shows less than a half knot to the southeast, although the agreement is only fair. The sea anchor shows that at a depth of 25 meters the velocity has increased to nearly a knot and is flowing almost due east. It might be inferred from this that the change in direction started at the surface and was working down.

Furthermore, on the basis of the GEK data it would appear that the original strong eastward flow was still maintained close to the Cuban Coast, and that the water still turned southward south of Guantanamo Bay and flowed out between Haiti and Jamaica. Whether this means that the change in flow spread outward from the Jamaica coast and had not yet reached the Cuban Coast by 8 April, or whether this strong eastward flow close to the Cuban Coast is part of the general circulation is not known.

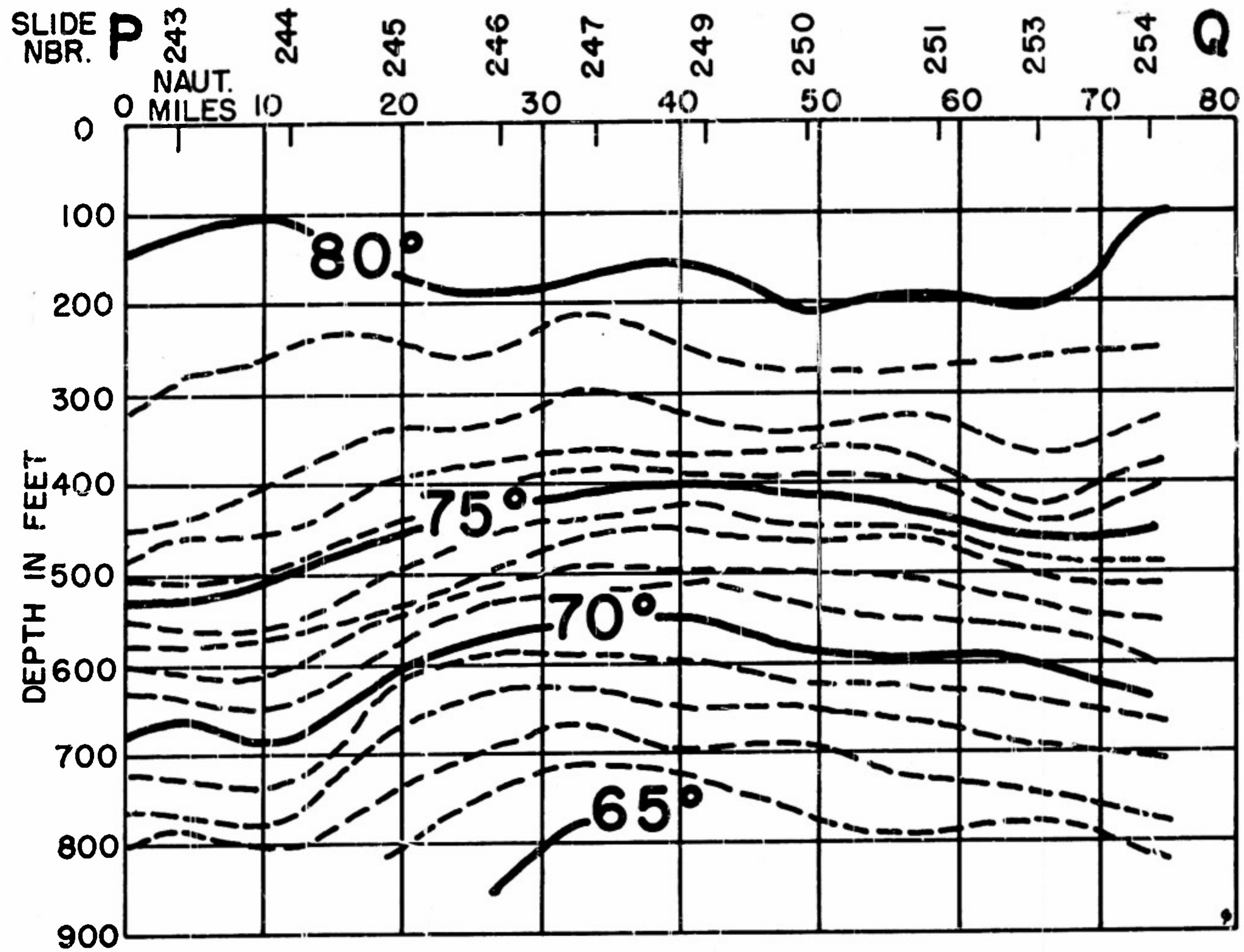

Fig. 15

Second BT Profile, Jamaica to Cuba 7 April

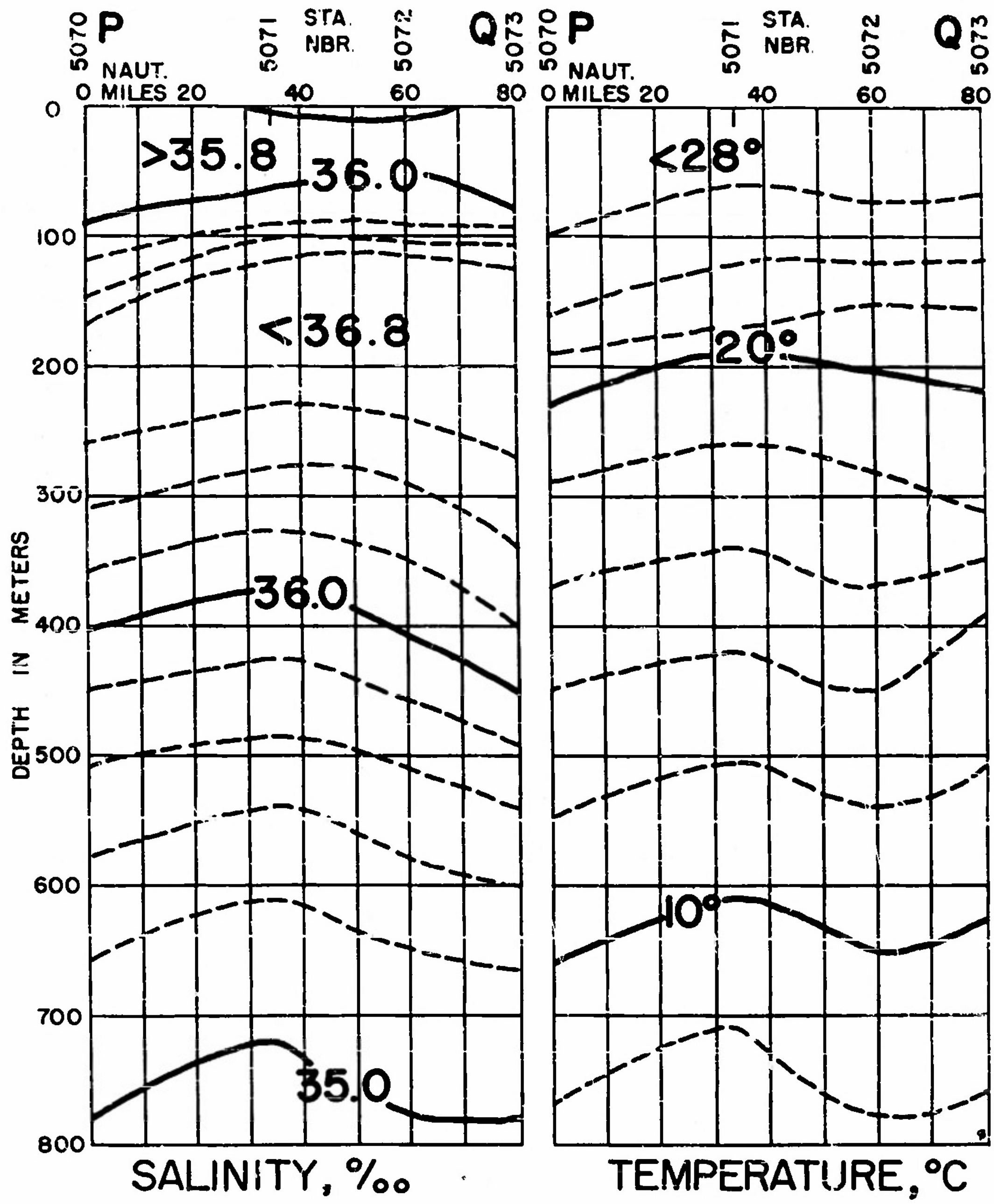

Fig. 16

ATLANTIS Salinity and Temperature Profiles, 7 April

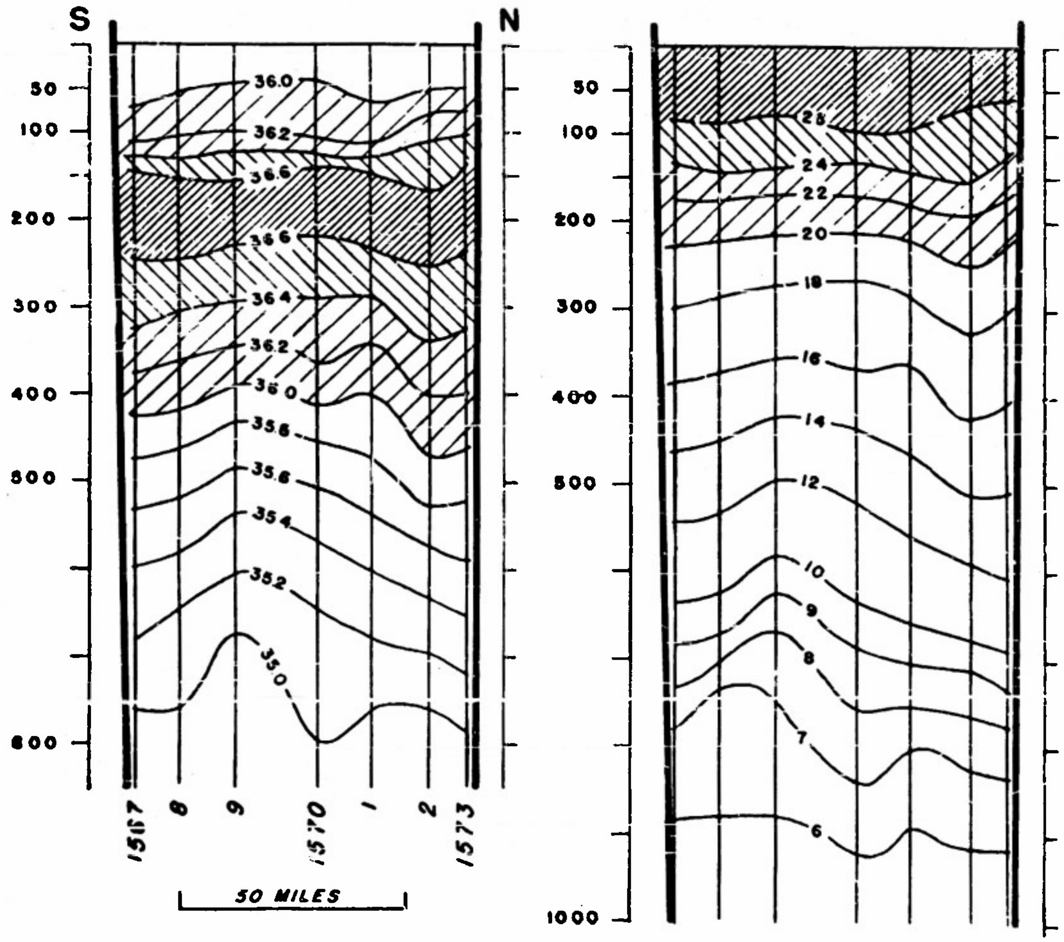

Fig. 17

Parr's Salinity and Temperature Profiles

Sea anchor observations were made at each hydrographic station. With the exception of station 5071 there was no measurable change in current with depth at any station. Because of problems encountered with this method of measurement, "no measurable change" can be taken to mean no changes greater than 0.2 knots.

A parachute subsurface drag measurement was made close to the Cuban Coast at a depth of 200 meters on the morning of 8 April from which a calculated velocity of 10 cm/sec in the direction of 309° T was obtained. It appears therefore that the eastward flow along the Cuban Coast at this time was shallow.

GEK measurements made during this period show occasional strong currents whose direction is almost random. Perhaps what was happening during this period was that the strong, rather large scale, and relatively coherent flow observed during the first half of the cruise had broken down into an eddy system whose dimensions were too small to be well defined and described by the techniques used.

Transient Nature of Currents

It was believed that local fisherman might be able to contribute considerably to our knowledge of conditions along the coast, so about ten fisherman along the north shore of Jamaica, and at Santiago de Cuba were asked about the surface currents as they found them. The consensus was that the currents could run either way, and it was not possible to predict which way they might be running even a day in advance. However, the current might run in one direction for as much as fifteen days. None of them knew of any correlation with either the wind or the moon.

It should be stated, however, that there is no deep water fishing in the area studied, and that the currents alluded to were strictly coastal.

Th... was general agreement that if there was an appreciable current in this area these fishermen would know of it, if only as local lore based on the experience of past and present generations.

Various operating personnel at NOB, Guantanamo, confirmed the variability of currents in these areas. Even the Navy information, however, was largely confined to the coastal areas near Guantanamo Bay. Information from the coast pilot tends to demonstrate the variability of the currents in this area.

Pertinent extracts from the Hydrographic Coast Pilot of West Indies, Vol. I, are:

6-2 Navassa Island - off Lulu Bay on the NW corner of the Island a current sets along the shore in a NW direction with a velocity of 1 to 2 knots, changing its direction to west at the last of the ebb. (Note that during the first half of our cruise the surface currents were 1 to 2 knots towards the SE.)

6-4 Morant Cays - The currents encountered by vessels in the vicinity of Morant Cays vary greatly both in set and rate; the rate is sometimes as great as 3 knots. The current varies so greatly as to preclude the possibility of giving any exact information regarding it.

6-6 Jamaica - Vessels approaching from the NE passage should make Navassa Island and then set course to weather Morant Point, bearing in mind the fact that the current often sets strongly to the westward.

Navassa Island Chart HO 1487 notes: "The current generally sets to the northwest. The wind seldom blows from the westward."

Drift Bottles

An essential part of the current program was the dropping of 360 drift bottles. While the information obtained by drift bottles is of considerably different character than that obtained by instantaneous current measurements they can be very useful for showing long term trends of the surface water.

Figure 18 shows the stations where drift bottles were thrown over. Six bottles were dropped at each station. The heavy lines indicate the probable mean path taken by the bottles which were recovered. The time in days from launching to retrieving is given. There is of course no reason to believe that the bottle drifted for the entire length of time indicated, since this includes whatever time it spent on the beach before being retrieved. The recovery of 18 out of 360 bottles is considered very high in view of the relatively uninhabited coasts along which the drops were made.

It is usually difficult to draw many conclusions from a small number of drift bottle returns and this experiment was no exception. The fact that 4% were found would lead one to think that a fair percentage of them went ashore in local waters. Only bottle #22 moved to the eastward. Most of them moved to the southwest.

While 8 bottles were found on the south coast of Jamaica, it is questionable whether this is due to a concentration of bottles or due to having more people along the beaches who could see the bottles.

The bottle from station 28 averaged 6 miles a day on its way to the Florida Keys. From previous drift bottle work it seems likely that additional bottles will be found along the Gulf Coast.

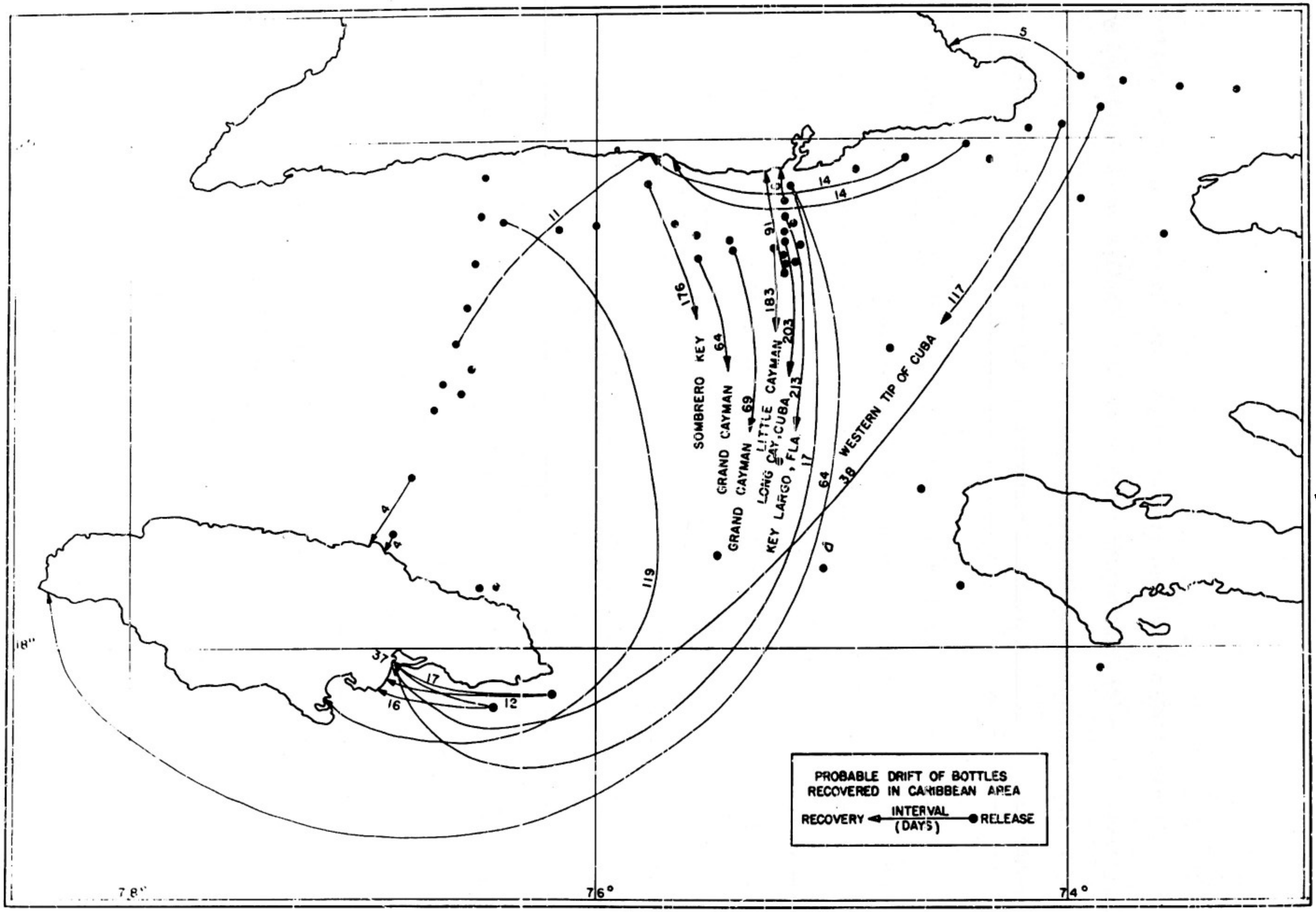

Fig. 18

D.:ift Bottle Trajectories

Discussion

In oceanography prior to the last decade observations were usually made at widely spaced intervals, partly to speed up the large scale survey problem, and partly because oceanic currents were thought to be fairly wide, slow and steady. Conclusions by Parr (1936), as shown in figure 19 are typical of these. During the past decade there has been an increase in the detailed investigations of smaller and more rapid phenomena. These investigations have usually shown that currents are faster, streakier, and less stable than had been suspected.

The measuring program just conducted has certainly shown that a more detailed survey produced a more complicated picture. This in itself was not surprising. However, the fact that such large non-tidal transient currents existed came as a complete surprise. The one inescapable factor in any discussion of this current picture is that we were dealing with a non-tidal transport of water that may be comparable in magnitude to the Florida current.

Because so strong a flow continued for a week or more it does not seem possible that the driving forces could have originated within the Eastern Cayman Sea. It is therefore assumed that we have to go outside of the Eastern Cayman Sea to find an explanation. It may be that the real origin of the transients must be traced to conditions in the open sea to the east of the lesser Antilles. However, the Caribbean itself, seems large enough to have a locally generated current system which could produce the observed phenomena.

Wind Stress in the Caribbean: In order to arrive at average values of wind and wind stress over the Caribbean, the sea level atmospheric pressure difference between San Juan and Trinidad, and Guantanamo Bay and Panama

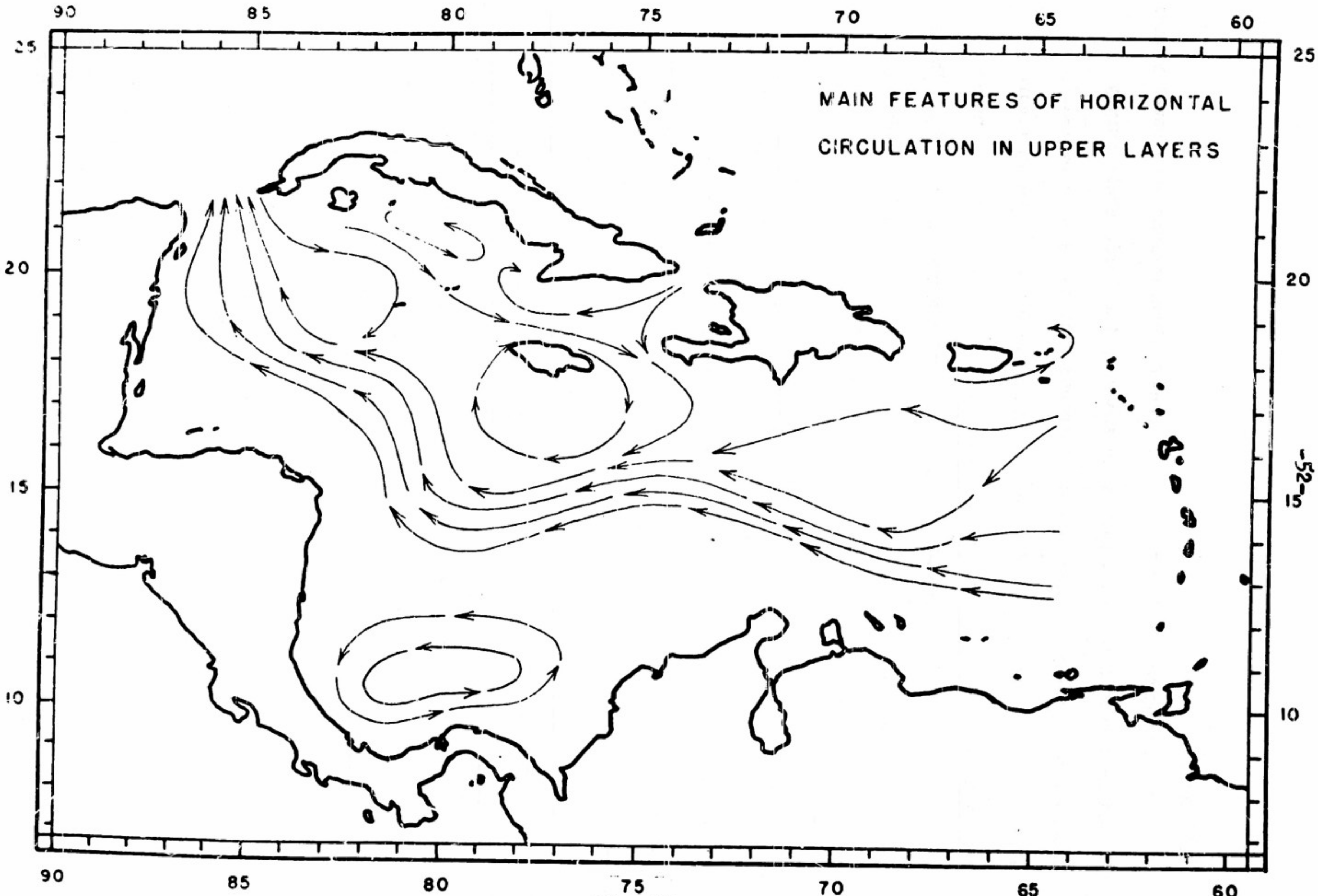

Fig. 19

General Circulation after Parr

(see Fig. 1) were averaged and plotted for the months of January, February, March and April. These average differences are shown in figure 20 along with an average sea level wind speed which is computed as 80% of the zonal geostrophic wind. In The Oceans, (Sverdrup et al, 1946) figures on wind stress for a rough surface give a wind stress in gm/cm/sec^2 of about .028 V^2 meters/sec or .007 V^2 knots. In tabular form this is:

Table III

Wind Speed knots	Wind Stress gm/cm/sec^2	MT gm cm/sec
8	.45	4×10^{20}
12	1.0	8
16	1.8	16
20	2.8	24
24	4.1	35

The third column is the momentum transfer per day over the 10^6 sq. km. of the eastern half of the Caribbean. It can be seen that the daily momentum transfer over half of the Caribbean is large compared to the measured flow of .2 x 10^{20} gm cm/sec which passed between Jamaica and Cuba each day. We concur with Parr and Dietrich that the trade winds pile up water in the western Caribbean due to the constriction of the Yucatan Channel. It is assumed that this is effective in deflecting at least part of the wind driven equatorial current to form the large eddies south of western Cuba which they describe. We propose that whether the eddy encircles Jamaica or not might be very dependent upon the strength of the equatorial current or upon any large north-south fluctuations in the position of the Equatorial Current.

Inertia Current: The average wind for the first two weeks of March was about 14 knots as compared to 8 knots for the latter part of March and first half of April, (Fig. 20). This means (Table III) that about 8 x 10^{20} gm cm/sec

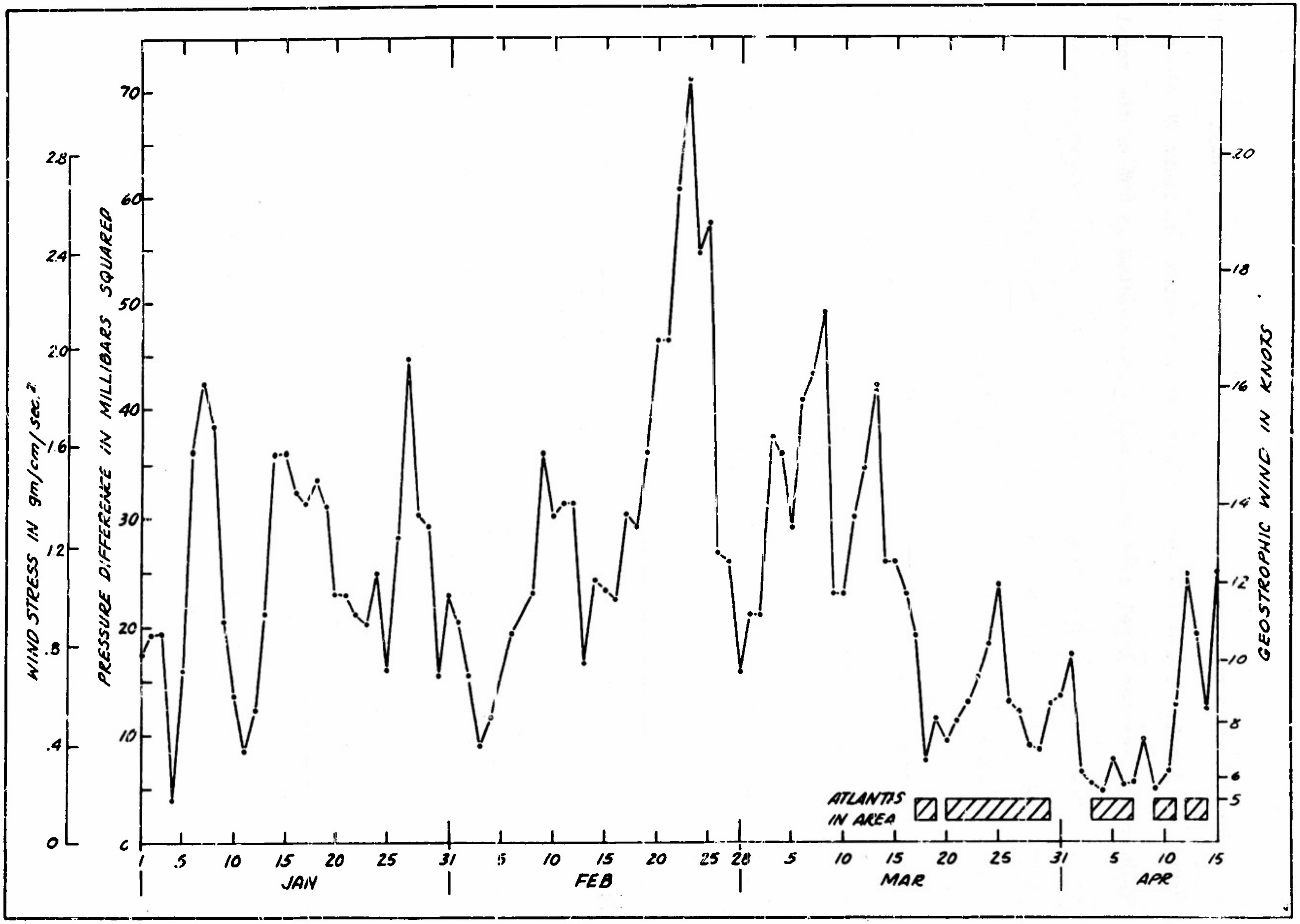

Fig. 20

Wind Strength over the Carribean

more momentum was transferred to the water daily during the first half of March than during the next month. An estimate of the amount of momentum in the counter current that passed between Cuba and Jamaica each day is 0.2×10^{20} gm cm/sec, only a fraction of the difference in momentum transferred to the water by the increased trade winds.

If the counter current is caused by an increase in the equatorial current it is expected that such a counter current would not begin to flow until a few days after the wind picked up, nor would it be expected to stop the moment the trade winds slacked off. A rough calculation shows that a reasonable excursion time for a water particle travelling in the Equatorial Current south of Jamaica, around the western tip of Jamaica, and then returning via the observed Cayman Counter Current to the north side of Jamaica could hardly be less than seven days and might easily be thirty. However, it is questionable whether there could be a true lag of two weeks between the slackening of the wind and the stopping of the current.

Venturi Action: Another mechanism which might also alter the current flowing between Cuba and Jamaica is associated with the north-south position of the Equatorial Current. Its average position according to Dietrich is about 100 - 150 miles south of Jamaica. Experience of the past ten years has shown that the N-S position of the Gulf Stream may vary by 50 miles, and it seems reasonable to expect the Equatorial Current to shift also.

If it should move its main axis up close to the coast of Jamaica and Haiti then it might easily produce a venturi action with the low pressure end at Navassa passage and the high pressure end at Cape Cruz, Cuba.

Whether one called this a venturi, an eddy or a counter current may be debateable but it would seem that such an action could produce a steady state counter current in the Cayman Sea as long as the Equatorial Current remained near the Haitian and Jamaican coast.

In order to be very effective in producing a venturi effect the Equatorial Current would probably need to be more sharply defined than we have presumed it to be on the basis of past measurements and thinking. This is not too unreasonable in view of the fact that earlier hydrographic work in the Caribbean area did not approach the detail with which the Gulf Stream had been studied.

Release of Static Head: In searching for other possible mechanisms a calculation was made to see if the current from the west could have been produced by the slackening of the east wind and subsequent back flow of water which had been previously piled up in the western Cayman Sea. While the strong winds of early March must have piled considerable water into the western Caribbean, rather simple computations show that this could not have accounted for even a fraction of the total easterly water flow measured. For example: if one assumes the water was piled up 1 meter deep over 600,000 sq. km. of the western Caribbean, and then ran off at the rate of 10×10^6 cubic meters/sec. it would have run off in 24 hours or less. It would thus appear that the western Caribbean couldn't possibly have held enough water to provide the observed flow for five to ten days.

* * * * * * *

In concluding this discussion there are several points that should be made:

(a) While there is probably plenty of potential driving force in any of the above explanations there is no reason to suppose that it is the operation of only one of them which entirely governs the current system in this part of the Caribbean.

(b) The fact Jamaica and Haiti serve to channel the flow may mean that the velocities observed in this area are greater than they would otherwise be.

(c) The Cayman Counter Current is probably not a rare phenomena, but it is difficult to guess whether it occurs many times a year.

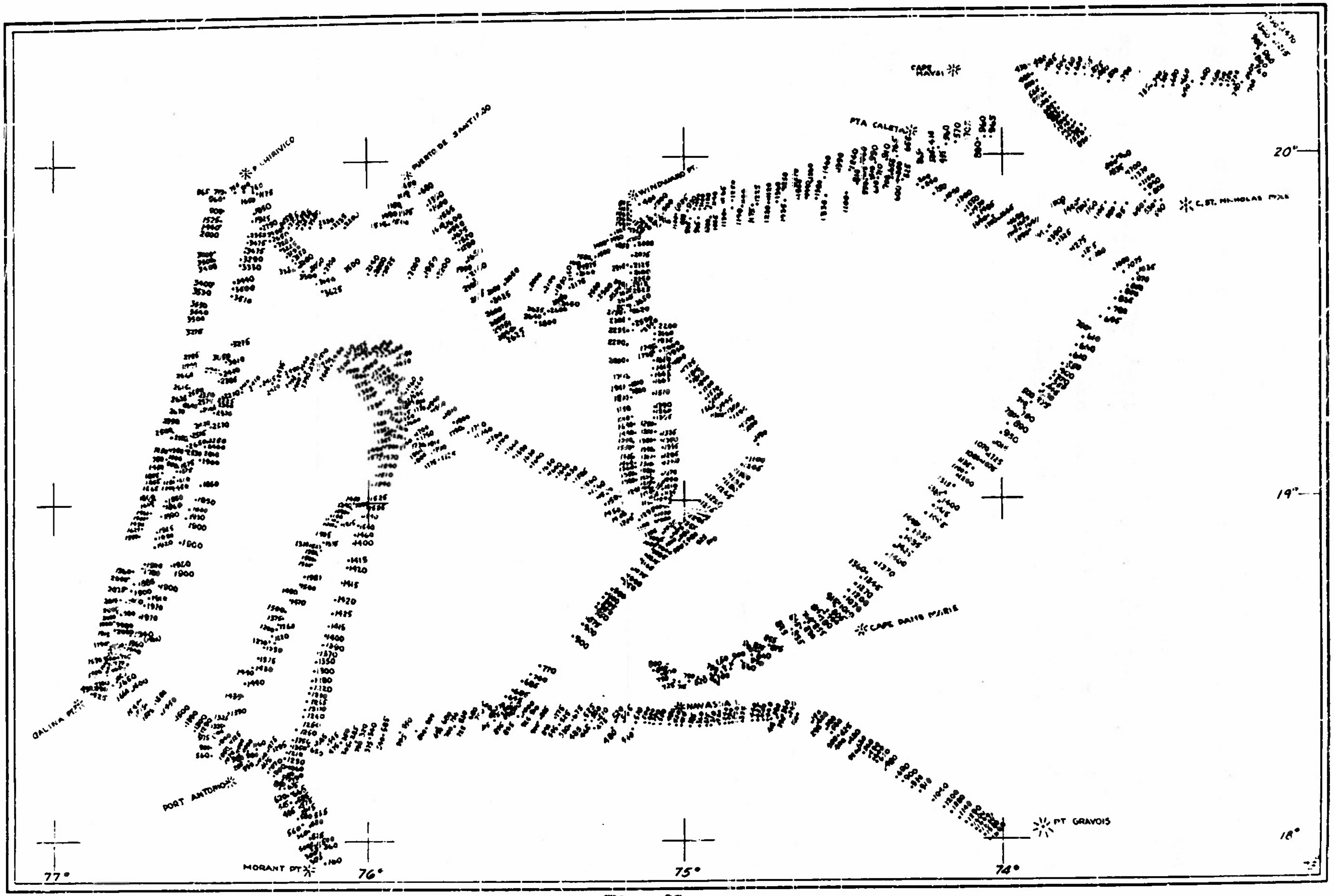

Fig. 21

Bathymetry of the Area

PART III

MISCELLANEOUS OBSERVATIONS

Considerable time on the trip was spent making other oceanographic observations. For convenience these are lumped in a miscellaneous category.

Bathymetry

Preparations for this trip included a study of available charts of the area for selection of various underwater landmarks for navigation purposes and for selection of areas for drift studies. Continuous fathograms were taken in the area and have been forwarded to the Hydrographic Office. A plot of the data is shown in figure 21.

1. The 300 fathom shoal reported to be in the vicinity of 19°-18' N, 75°-53' W, was not found. The minimum depth found from several crossings was 1210 fathoms. It is quite possible that the ship could have missed a sharp peak.

2. The 900 fathom shoal reported to be in the vicinity of 19°-14' N, 75°-07' W, yielded a minimum depth of 1260 fathoms on three crossings. Here again we could have missed a sharp peak.

Sill depths for this area are given in figures 22 and 23. These depths were taken from Hydrographic Office charts.

Diffusion

At 2200 on 1 April a group of ten surface drogues was released. The drogues were at five meters depth and were similar to those described in Part I. They were released one at a time while the ship drifted. The average initial distance between the drogues was 20 yards. At dawn the

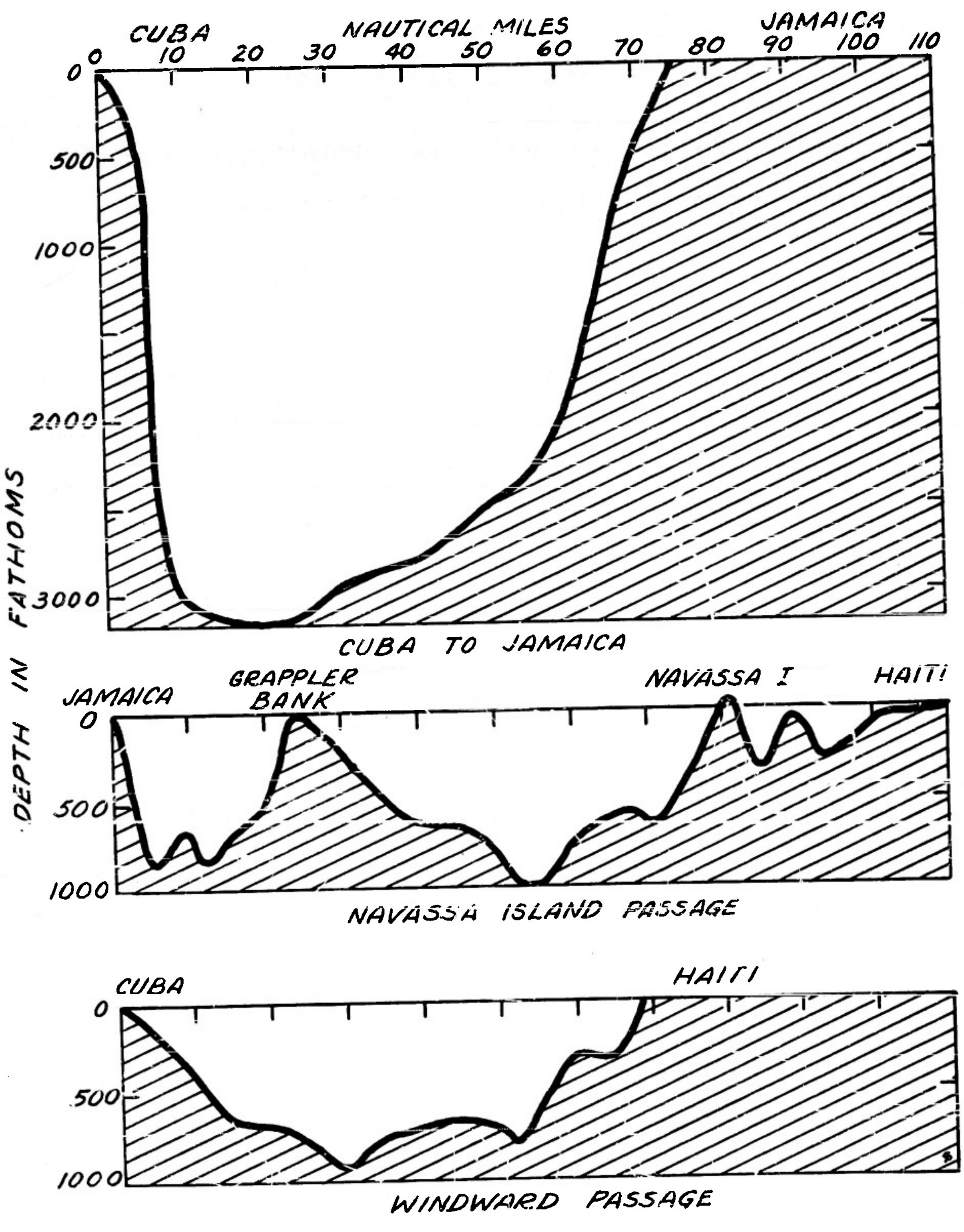

Fig. 22

Sill Depths

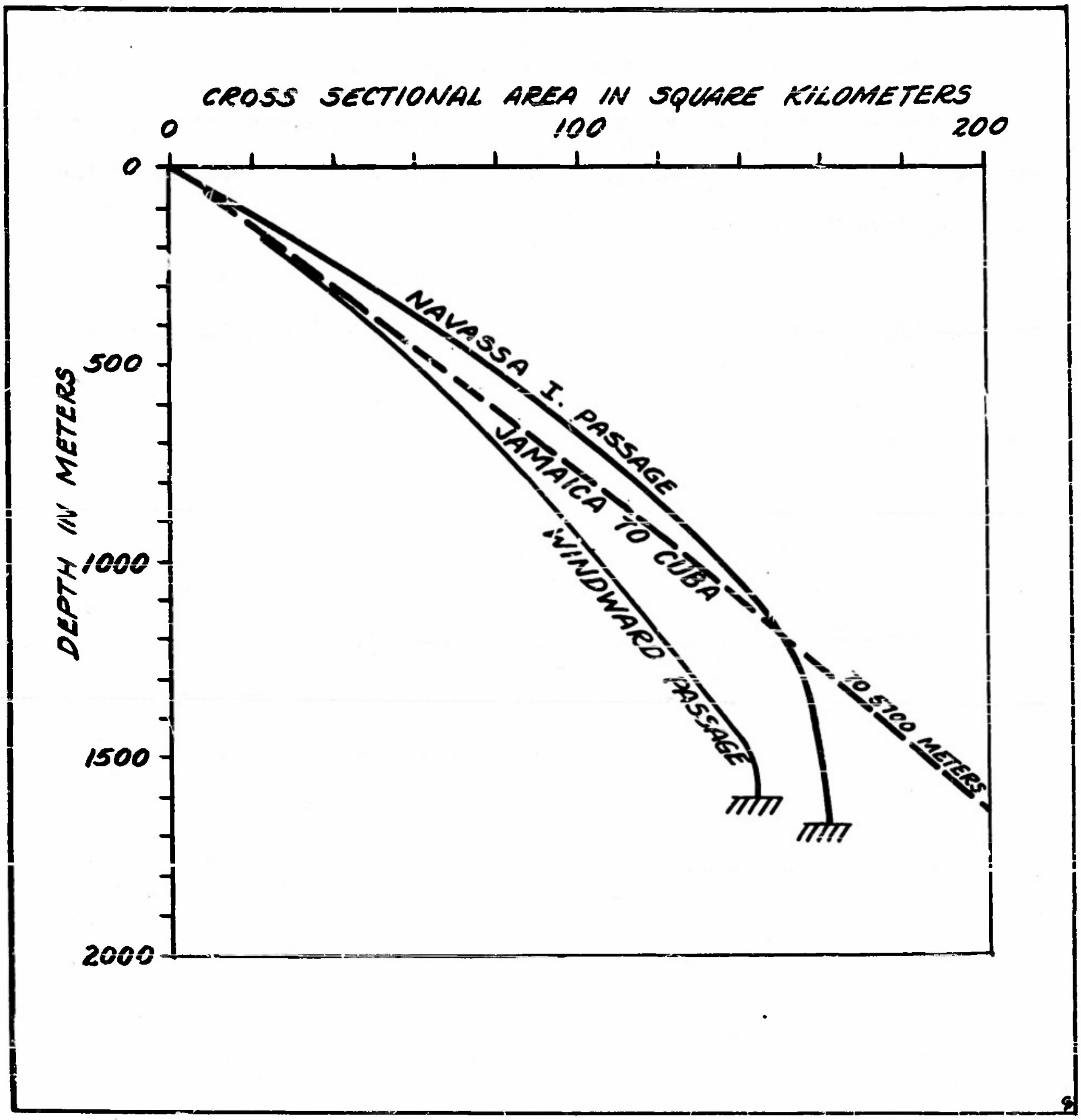

Fig. 23

Sill Area versus Depth

next morning five drogues were found, grouped in an area of about 200 yards square. None of the other five were to be found, although a thorough search of the area was made. It is assumed that they sank. During the day a plot was kept of the relative position of the buoys. At about 1400 one of the remaining five buoys sank.

Possibly the most important point to make about this experiment, other than the high attrition rate, is the following: The drogues were tracked for twenty hours. During that time they drifted 20,000 yards in a direction 030° T. The wind was 070° T, Force 3-4. At the end of twenty hours all buoys were in a rectangular area 1000 yards wide (across current), and 400 yards long (along the mean current).

It was noticed that the rate of separation of the buoys seemed to increase as the distance between buoys increased. Richardson and Stommel (1948) showed that when the distance between particles was of the order of one to ten meters the mean rate of horizontal dispersion was proportional to $\ell^{4/3}$, where ℓ is the distance between two particles.

It is realized that the number of drogues was too small, and the method of observing distance between buoys was too crude and spasmodic to make any such statistical analysis very significant. However, to our knowledge, no tests have ever been made of this next scale, where the distance between particles is more than a hundred meters. For this reason an attempt was made to analyze the data in a manner similar to that described by Richardson and Stommel.

The only conclusion that can be drawn is that there is nothing in the experiment conducted which would lead one to believe that the "four thirds law" does not hold for this scale of turbulence. The results are shown in Table IV. It can be seen that the rate of diffusion appears to be more on the order of "five thirds", but this discrepancy can be accounted for (if indeed it has to be) by the fact that random errors in measurement tend to make the rate of dissipation appear greater than it really is.

Table IV

$$\frac{d\overline{(\ell)^2}}{dt} = k(L)^x$$

ℓ meters	x
100	1.47
250	1.48
475	1.62

Biological Observations*

All of the biological observations on the present cruise were made incidentally to the program of current studies and an unfortunate result of the large amount of steaming was that little time was available for fishing at depth.

The general impression received of the Eastern Cayman Sea was one of comparative barreness. Hours passed in this area during which no living things other than plankton organisms and fellow shipmates were seen. Sighting a bird became an occasion. Whales were seen only once. Surface trolling by techniques proven effective on recent ATLANTIS cruises yielded no fish in this area.

The most conspicuous inhabitant of this area is the white-tipped shark, *Carcharhinus longimanus*. Generally, with the vessel hove to, one or more sharks could be attracted be means of large baits. During the course of one

* This section is contributed by Dr. R. H. Backus.

day, (18 March), spent in the Windward Passage, six or seven sharks were continuously around the vessel, yet throughout the day of 25 March, (hove to 10 - 15 miles off the coast of Cuba west of Santiago), none was seen. Fifteen white-tipped sharks from 5 - 8 feet in total length were hauled aboard the ATLANTIS for examination. Of these, fourteen were males. Bigelow and Schroeder (1948) reported the capture of a female in May off the Cuba coast which contained embryos ready for birth. This suggests that the spring months are the season of reproduction. It is possible that at this time the females seek some special habitat which makes them unavailable to surface hook and line fishing in the open sea, thus explaining the disproportionate sex ratio. The single female caught on the present cruise contained eggs of various sizes, (the largest about 1½ inches in diameter) but no embryos.

Although this species is generally thought to be more or less strictly pelagic one was observed in the outer part of the harbor of Guantanamo Bay, and several more were caught in the immediate offing.

In addition to the specimens of C. longimanus taken aboard, four juvenile specimens of Carcharhinus falciformis were captured. No other species of sharks were observed throughout the cruise. The conditions of the genads, stomach contents, and certain anatomical details were observed in all sharks caught.

Occasionally groups of from four to six dolphin (Coryphaena hippurus) were seen in company with white-tipped sharks. Generally, several pilot-fish (Naucrates ductor) were present on these occasions. Frequently Remora remora and occasionally Remora albescens, shark-suckers, were attached to the white-tipped sharks.

Now and then, solitary fishes were seen at the surface when sea states were low enough to afford good visibility. These were generally associated with Sargassum weed which was not abundant in this area. On one occasion in connection with the current studies, a pilot balloon, inflated to a diameter of about 4 feet, was released at the sea surface with a drogue attached. The balloon was returned to after an absence of an hour or two. In the interim, two fish had taken "shelter" under the balloon. It is suggested that such a balloon with appropriate fishing gear attached might be an excellent way to collect solitary pelagic fish, many of which are attracted to floating objects.

Flying fishes were uncommon in this area save in the coastal waters off eastern Jamaica where they were abundant.

Man-o'-war birds and yellow-billed tropic birds were seen from time to time throughout the area. In the Windward Passage on 18 March, several unidentified shearwaters (probably greater shearwaters) were seen. On 31 March while hove to just off Navassa Island, many boobies (Sula spp.) were observed, but none were seen to fish.

The only whales sighted were a group of about six, probably blackfish (Globicephala macrorhyncha), seen in the Windward Passage on 18 March.

Several short vertical plankton hauls were made with a meter stramin net during hours both of light and darkness. Plankton organisms seemed abundant enough to warrant more in the way of animals higher in the food chain. Medusae, arrow-worms, and copepods were dominant in these hauls.

Bathythermograph Sections

Bathythermograph observations were made every hour or hour and a half whenever the ship was underway. It had been hoped that an internal wave station could be set up during one of the deep buoy stations, but the buoys separated too quickly from each other to allow the ship to remain stationary for any extended period of time. The 900 foot instruments were used throughout, and additional sections are shown in figures 24 and 25.

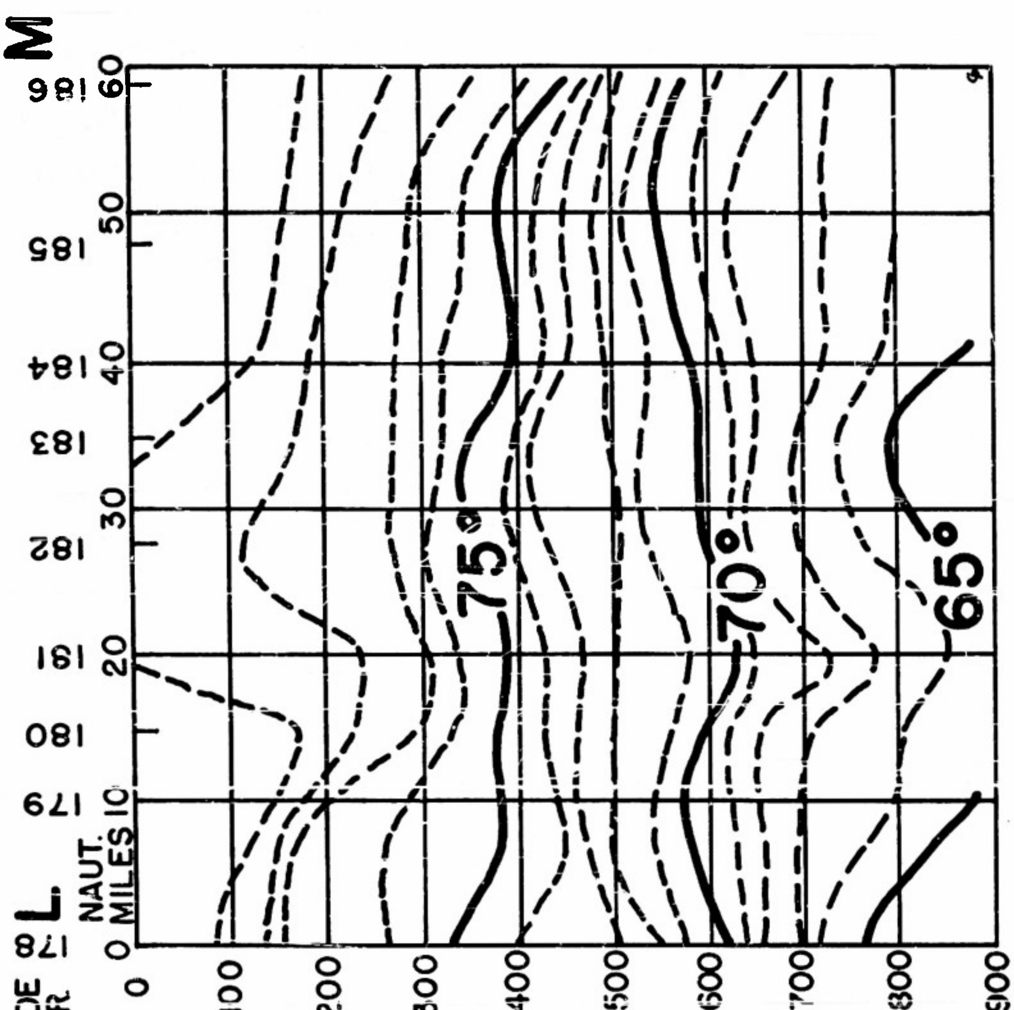

Fig. 24

BT Profile, Windward Passage

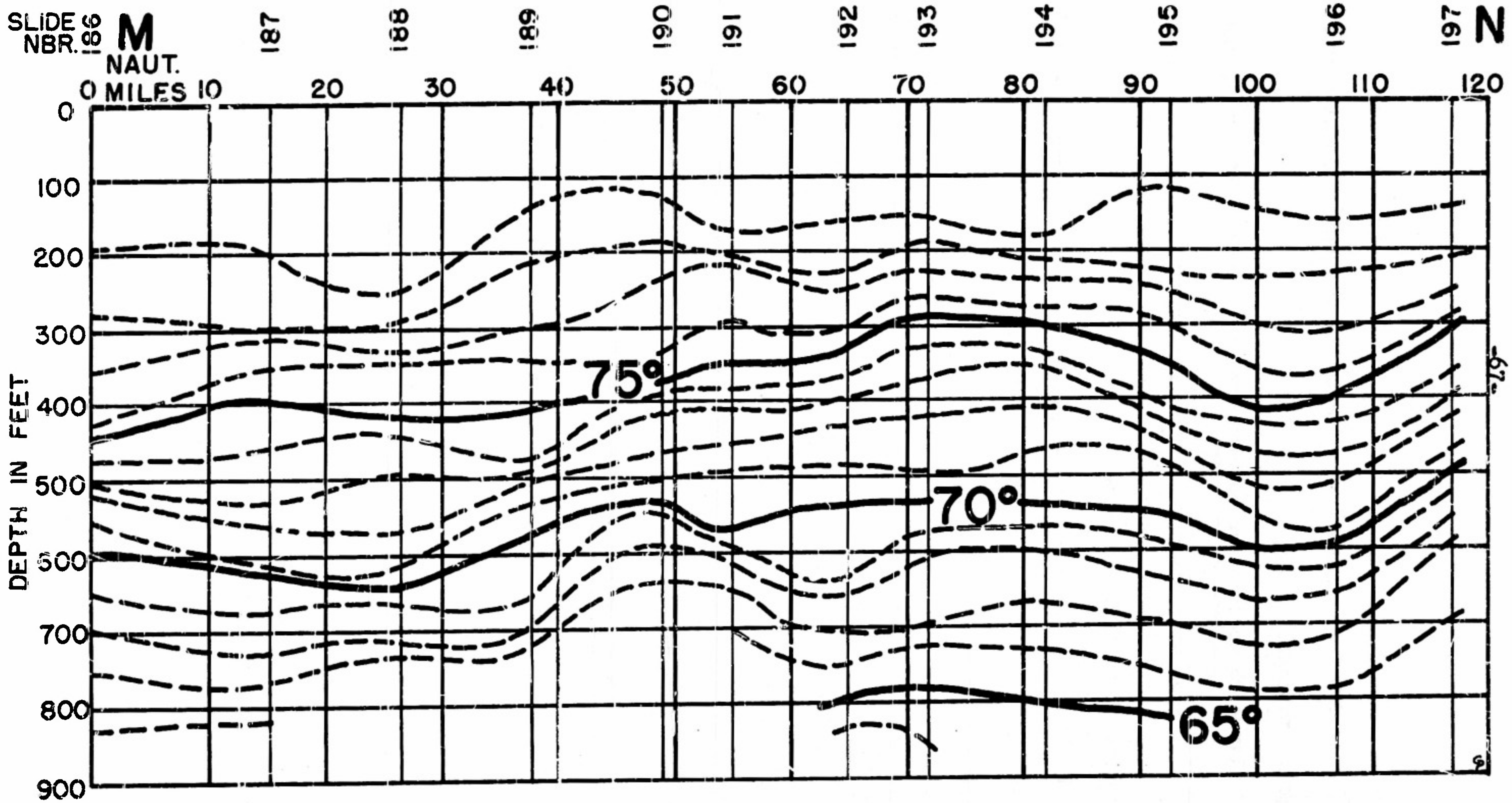

Fig. 25

BT Profile, Gonave Bay

A 13,000 foot BT was lowered with the bottom bottle at each of the hydrographic stations.

Figure 26 shows a typical temperature versus depth trace, and the corresponding sound velocity versus depth curve.

Electrical Potential Measurements

While in Kingston we checked with the cable company to see if there was a submarine cable between Jamaica and Cuba which could be used to measure potentials set up between the two points by east-west motion of the water between. Officials at the cable company were most cooperative in explaining their installation and it appeared technically feasible to make measurements between Kingston and Santiago, Cuba. Proper recording equipment was not available so company authorities who might have been able to advocate time for this purpose were not contacted. It does however, hold great possibilities for future current studies in this area.

Conclusions and Recommendations

The conclusions and recommendations fall in two groups, those having to do with the experimental procedure, and those having to do with the area studies.

The use of floats, drogues and anchored buoys for measuring currents was extremely interesting and they are strongly recommended for direct measurements. The use of 24 foot parachutes makes it possible to reduce errors to a quite acceptable minimum. It is felt that the use of suitable radar reflectors on either the floats or the anchored buoys would have made the measurements considerably easier to obtain.

The most important finding was the unexpectedly large easterly water transport which exhibits time constants of at least several days and which reverses direction without a reversal of wind. It is believed that the generating

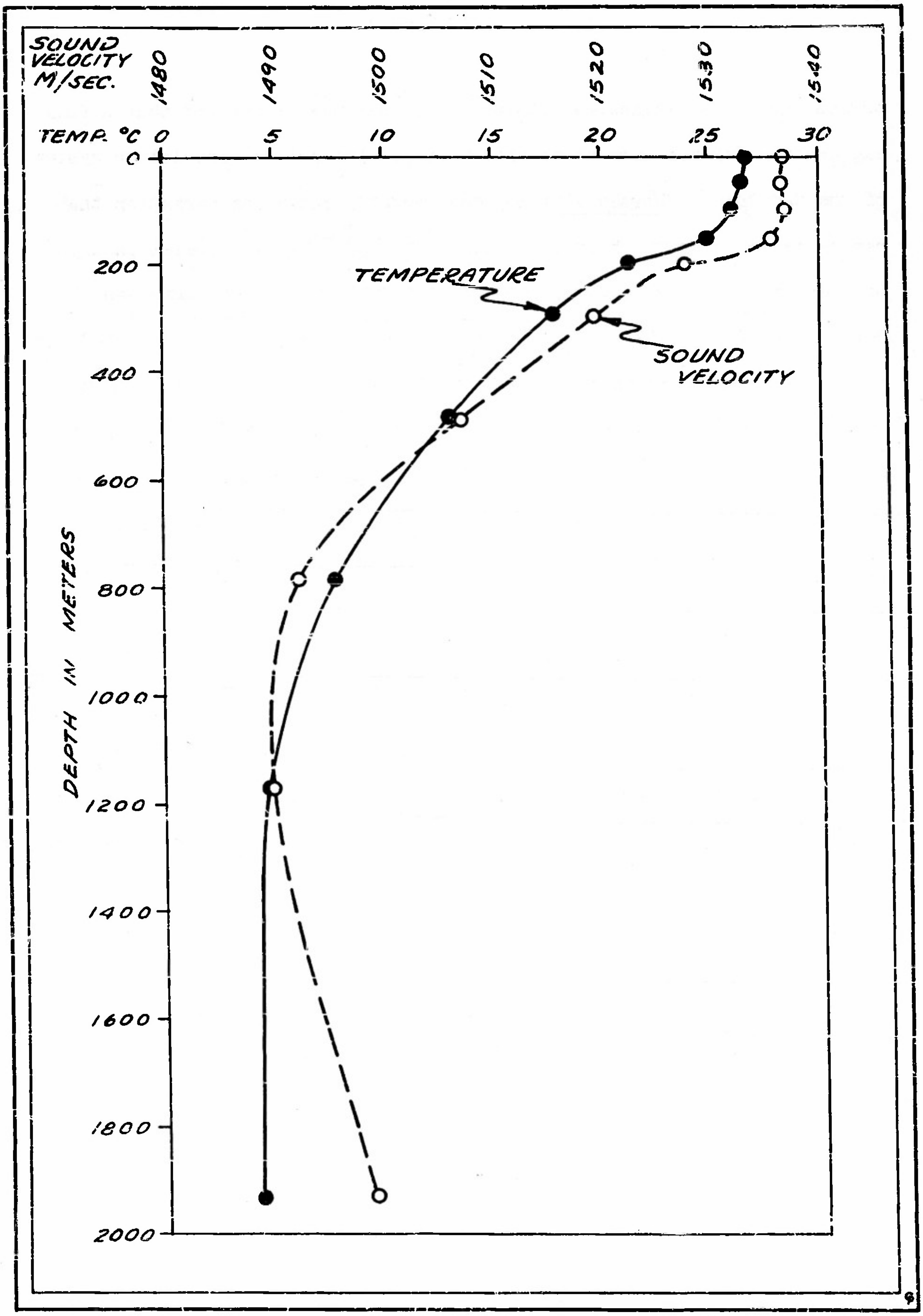

Fig. 26

Typical Temperature Depth Trace and Sound Velocity versus Depth forces must have originated outside the Cayman Sea proper and that a full explanation depends upon an understanding of the entire circulation system of the Caribbean. Wertheim (1953) has recently shown the variation that can be expected in the Florida Current. The possible interrelationships between the perturbations in the current structures in the Caribbean, Gulf of Mexico, and Straits of Florida offers a fascinating field of future study. One reason is that this is a scale of problem (the geometric mean between an estuary and the open ocean) which has not been adequately studied. A second reason is that it seems to the authors that this interrelationship is an important and essential link in the understanding of the Equatorial Current - Gulf Stream system. Several different types of observations would be useful.

It would seem advisable not only to continue monitoring the electric potential across the Straits of Florida, but also to set up similar observations between Cuba and the Yucatan Peninsula, and Cuba and Jamaica. These coupled with tide gage and wind data should certainly show the best time to conduct such tests and might in themselves reveal the driving forces. It is also probable that an oceanographer could spend several months at the Guantanamo Bay Navy Base and carry out a very fruitful investigation of currents in the area by riding ships and discussing the problem with navigators of ships in the area. It is also quite possible that the ships or aircraft in the area could periodically observe the behavior and location of several buoys anchored with an extra mile or two of scope.

It would seem likely that individual efforts in the above experiments during the next few years would open the problem up enough to show how a combined operation such as OPERATION CABOT could efficiently explore many details of the current system simultaneously. Such an expedition should study the flow of water in the Caribbean, Gulf of Mexico and the Florida Straits. It would seem highly desirable to have Texas A & M, the University of Miami, Woods Hole Oceanographic Institution, and the U. S. Navy Hydrographic Office cooperate in such a venture.

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